Design Study of RL10 Derivatives

Final Report

Volume II

Engine Design Characteristics

Appendices

Foreword

The appendices in this book contain detailed calculations, curves and substantiating data which support the information contained in Volume II - Engine Design Characteristics. Appendix I contains a description of the development of the RL10 ignition system. This information was included because the most advanced RL10 igniter design is identical to that used on the RL10 derivative engines and the data obtained during the development of this igniter is directly applicable. Appendix II describes the performance calculations used for the RL10 derivative engines. It includes a description of the JANNAF methodology used and the performance results obtained. Appendix III describes the computer simulations used to establish the control system requirements and define the engine transient characteristics. Also included in this appendix are curves obtained from the simulation runs which show the transient characteristics of various engine parameters during different transient modes. Appendix IV describes the computer programs used to define engine steady state cycle characteristics. It also includes cycle printout sheets for significant operating points for all of the baseline engines. Appendix V presents the Maintainability Engineering Layout Review Forms. These forms document the results of the reviews made of the engine component layouts to insure that maintainability requirements were adequately taken into account.

VOLUME II
ENGINE DESIGN CHARACTERISTICS
APPENDICES

CONTENTS

Appendix I

Development of RL10 Engine Ignition System

The torch igniter concept and hardware proposed for use in the RL10 derivative engines evolved during eight years of RL10 engine development. During this time period three basic design changes were made.

The initial RL10 design shown in Fig. I-1 utilized a direct spark ignition system. Its performance was found to be unreliable because the design did not insure that a combustible mixture ratio was present at the spark igniter tip.

As a result, an extensive research program was conducted in 1961 to investigate the ignition limits of hydrogen-oxygen mixtures and to develop an improved igniter system. This program is documented in Reference No. 1. As an aid to understanding the basic ignition characteristics of a spark ignited hydrogen-oxygen system, a series of static ignition tests were conducted. The effect of spark gap, energy level, propellant temperature and flame quenching upon the ignition envelope defined by unlit chamber pressure and mixture ratio were investigated. The static ignition envelope achieved by the selected RL10 spark gap and energy level with ambient propellants is shown in Fig. I-2.

In order to insure that the propellant mixture present at the engine spark igniter was well within the ignitable region defined above, a torch igniter system was developed. This system provides a flow of hydrogen and oxygen which is mixed in a annulus

around the spark igniter tip, ignited by the spark, and passes into the combustion chamber to ignite the main propellants as shown in Fig. I-3. The oxidizer flow is shut off during the acceleration to full thrust. This igniter, whose ignition characteristics are shown in Fig. I-4, is standard equipment for the RL10A-1, RL10A-3, RL10A-3-1, and RL10A-3-3 engines.

In 1963 a program was initiated to increase the reliability of the RL10A-3-1 ignition system previously described. This program is documented in Reference No. 2. This increase in reliability was to be accomplished by providing dual exciters and spark igniters and by eliminating the need for an oxidizer shutoff valve. The dual spark and exciter configuration provided a fail safe energy source and designing the igniter to operate at rated thrust with oxidizer and fuel flow eliminated the possibility of igniter damage due to valve leakage. Eight configurations were investigated during the development of the igniter system. The selected configuration, shown in Fig. I-5, provided an ignition envelope, shown in Fig. I-6. While this dual ignition system offered increased reliability it did not significantly improve the allowable range of ignition.

In 1965 a program was undertaken to provide an improved ignition system for the RL10A-3-3 engine then under development. This program, building upon the results of the previous programs, retained the dual spark igniter and continuous torching features while revising the igniter injection configuration to improve the ignition envelope. Results of this program were documented in monthly contractual reports such as Reference No. 3.

Four configurations were tested leading to the design shown in Fig. I-7. The fuel and oxidizer is ignited by a spark exciter assembly which provides a minimum of 20 sparks per second at an energy level of 0.5 joules. The total oxidizer flow is injected into the igniter through a single oxidizer element located in the upper end of the igniter chamber. Fuel flow is split. Part of the flow is delivered to a concentric slot surrounding the oxidizer injector element and the remainder used for igniter barrel cooling. The burned propellants are discharged into the main chamber through the igniter injector sleeve. As shown in Fig. I-8 the ignitable envelope was improved considerably over that of the previous design by moving the injection element closer to the spark igniter.

This final igniter configuration is standard equipment on the RL10A-3-7 engine and since it has been tested extensively under tank head idle start conditions it was selected for use on the RL10 Derivative II engines. Table I-1 documents one such series of tank head idle tests on an RL10A-3-7 engine at liquid, gas and two phase inlet conditions over a range of inlet pressure from 40 psia to 16 psia.

The results of the test series shown in Table I-1 were used in conjunction with an igniter/engine chamber rig test series to establish the main chamber ignition envelope shown in Fig. I-9. It should be pointed out that the main chamber ignition limit data defined during rig testing is a true chamber limit since it was obtained by varying the chamber conditions until a light was achieved with a continuously torching igniter. The engine tank head data defines a conservative chamber limit, however, since

it was obtained by simultaneous ignition of the chamber and igniter. The chamber ignition envelope is better than that indicated by the line of Fig. I-9 at low mixture ratios.

References

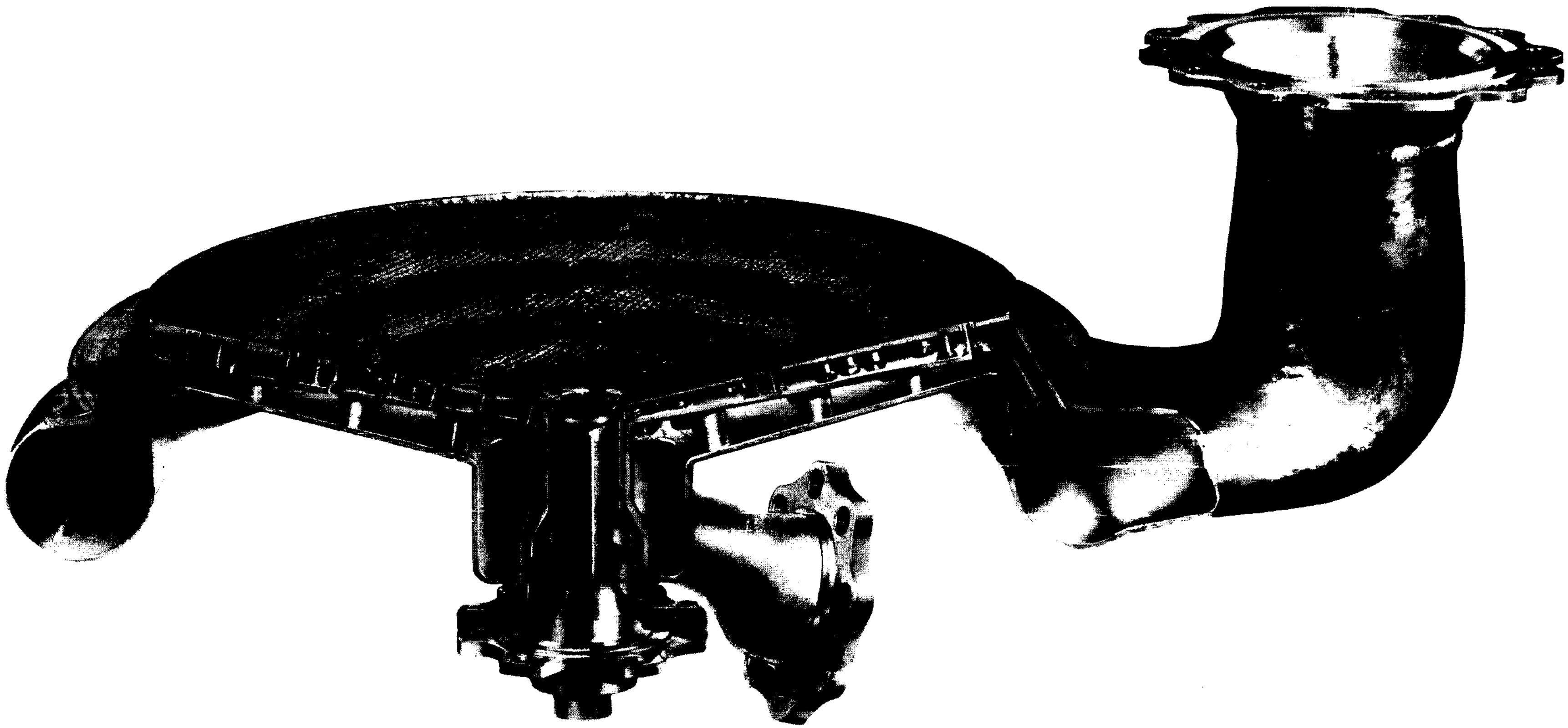
1. FR303, Development of RL10 Ignition System, 20 Nov. 1961
2. SMR FR1174, RL10 Dual Ignition System Development Summary, 10 Dec. 1964.
3. FR1405, Monthly Report, 21 July 1965.

TABLE I-1

Tank Head Idle Ignition Summary
FX-149

Run	Pump Inlet Conditions						Housing Temperatures		At Ignition		Remarks
	FPIP	FPIT	Phase	OPIP	OPIT	Phase	FPHT	OPHT	O/Fc	Pc	
239.01	25.3	39.9	2 Ø	29.2	174.9	2 Ø	328.	452.	2.2	.85	
240.01	28.5	40.9	2 Ø	21.6	169.1	2 Ø	368.	462.	2.0	.8	
241.01	25.6	47.6	GAS	24.9	184.8	GAS	423.	478.	2.0	.85	
242.01	21.5	50.6	GAS	22.3	187.1	GAS	396.	478.	2.4	.75	
243.01	16.5	63.7	GAS	20.9	195.8	GAS	348.	456.	3.6	1.1	
244.01	18.9	61.4	GAS	15.8	192.3	GAS	384.	458.	2.5	0.9	
245.01	24.9	39.9	2 Ø	19.8	167.4	2 Ø	218.	440.	2.4	.8	
246.01	27.4	40.7	2 Ø	22.5	169.0	2 Ø	210.	448.	2.1	1.3	
250.01	23.1	53.4	GAS	22.8	189.7	GAS	337.	440.	9.25	.7	EVACUATED JACKET START
251.01	25.5	43.2	GAS	23.8	187.6	GAS	298.	422.	Not Available		
252.01	34.4	42.2	L	23.2	170.2	L	305.	448.	2.58	.8	
253.01	23.1	55.7	GAS	21.8	NAV	GAS	337.	455.	Not Available		
254.01	40.6	42.9	L	22.2	169.6	L	Not Available		Not Available		
255.01	27.2	55.1	GAS	24.9	NAV	GAS	446.	448.	7.8	.72	EVACUATED JACKET START
256.01	25.7	40.1	2 Ø	27.3	199.3	GAS	265.	462.	8.9	.7	EVACUATED JACKET START
257.01	22.8	50.6	GAS	22.0	169.1	L	346.	449.	6.9	.45	EVACUATED JACKET START

LR115 INJECTOR CROSS SECTION CUTAWAY



PRATT & WHITNEY AIRCRAFT
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FLORIDA RESEARCH & DEVELOPMENT CENTER

FD 1231
21 OCT 60

Figure I-1

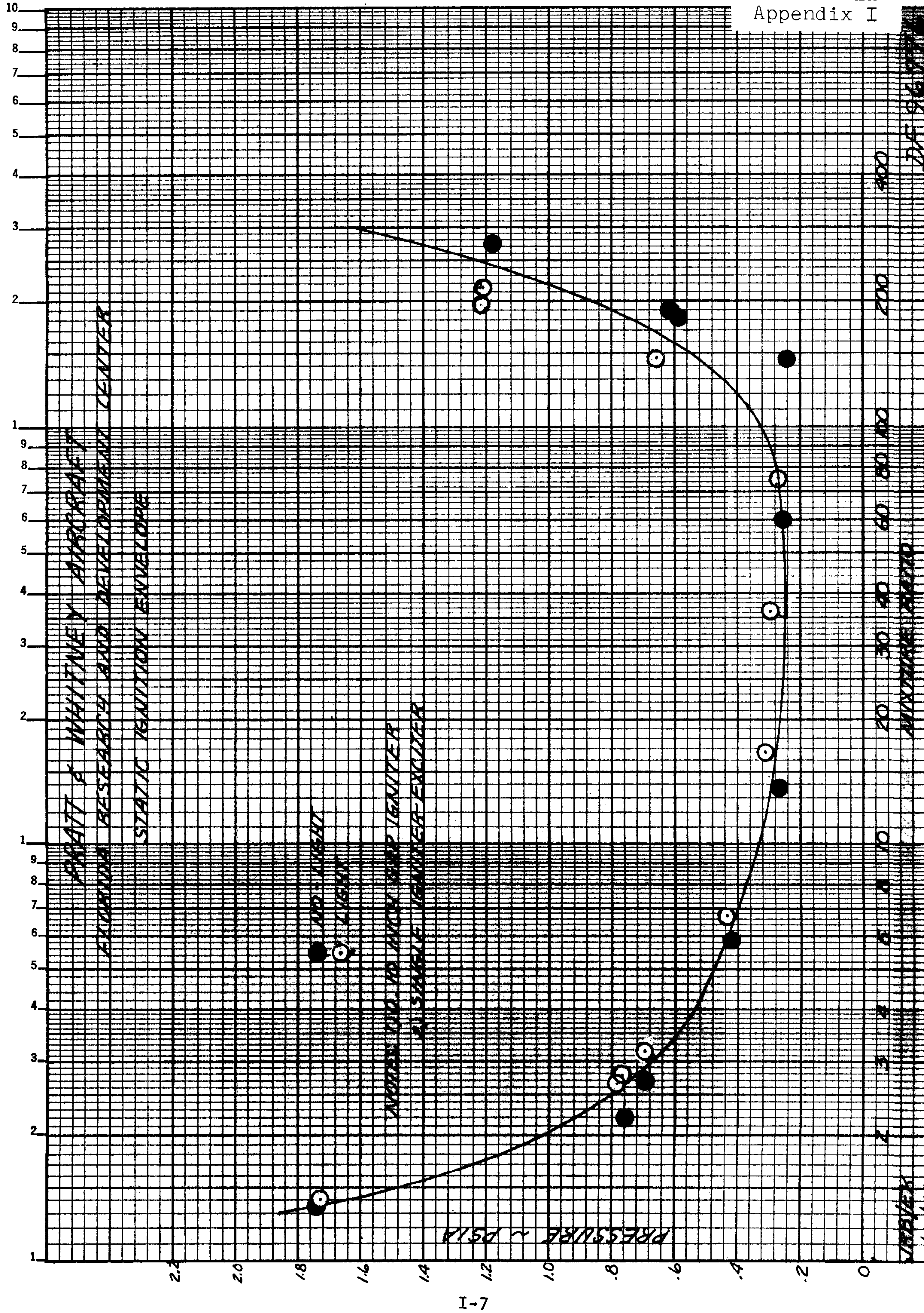
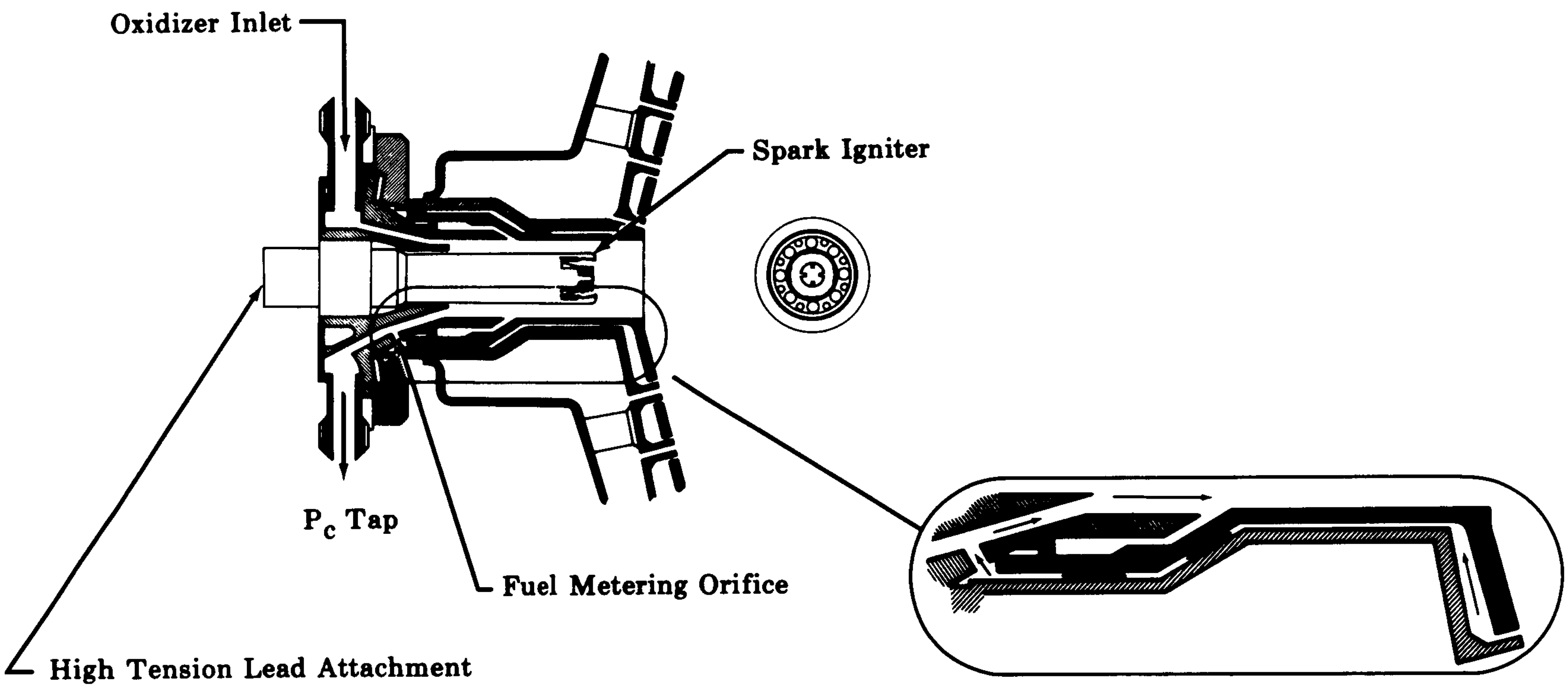

PRATT & WHITNEY AIRCRAFT
FLORIDA RESEARCH AND DEVELOPMENT CENTER
STATIC IGNITION ENVELOPE
NO-LIGHT
LIGHT
NOTES: (1) .10 INCH GAP IGNITER
(2) SINGLE IGNITER-EXCITER
PRESSURE ~ PSIA
MIXTURE RATIO

FIGURE I-2

RL10A-3-3 Igniter Assembly



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662502
FD 3134A

Figure I-3

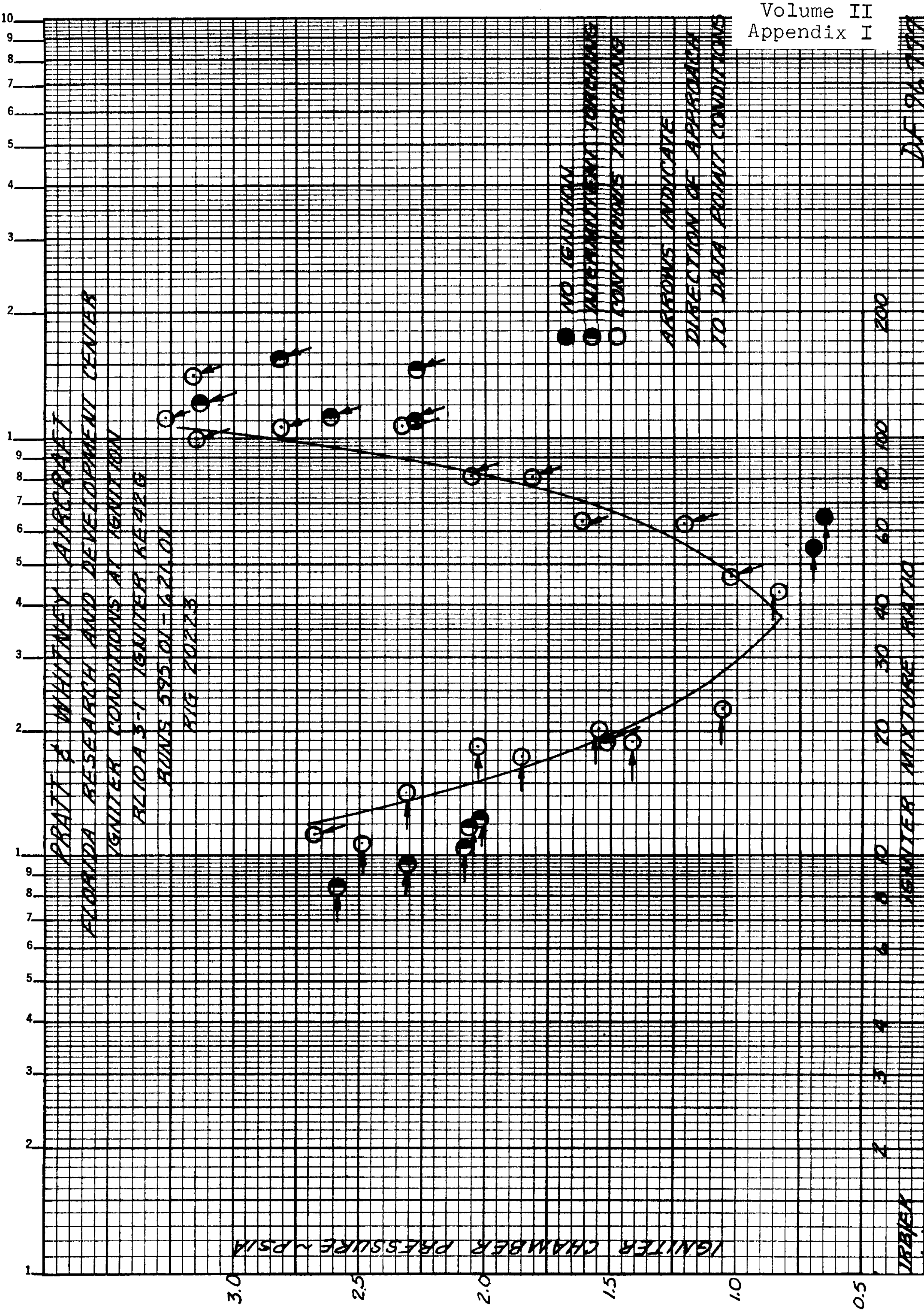
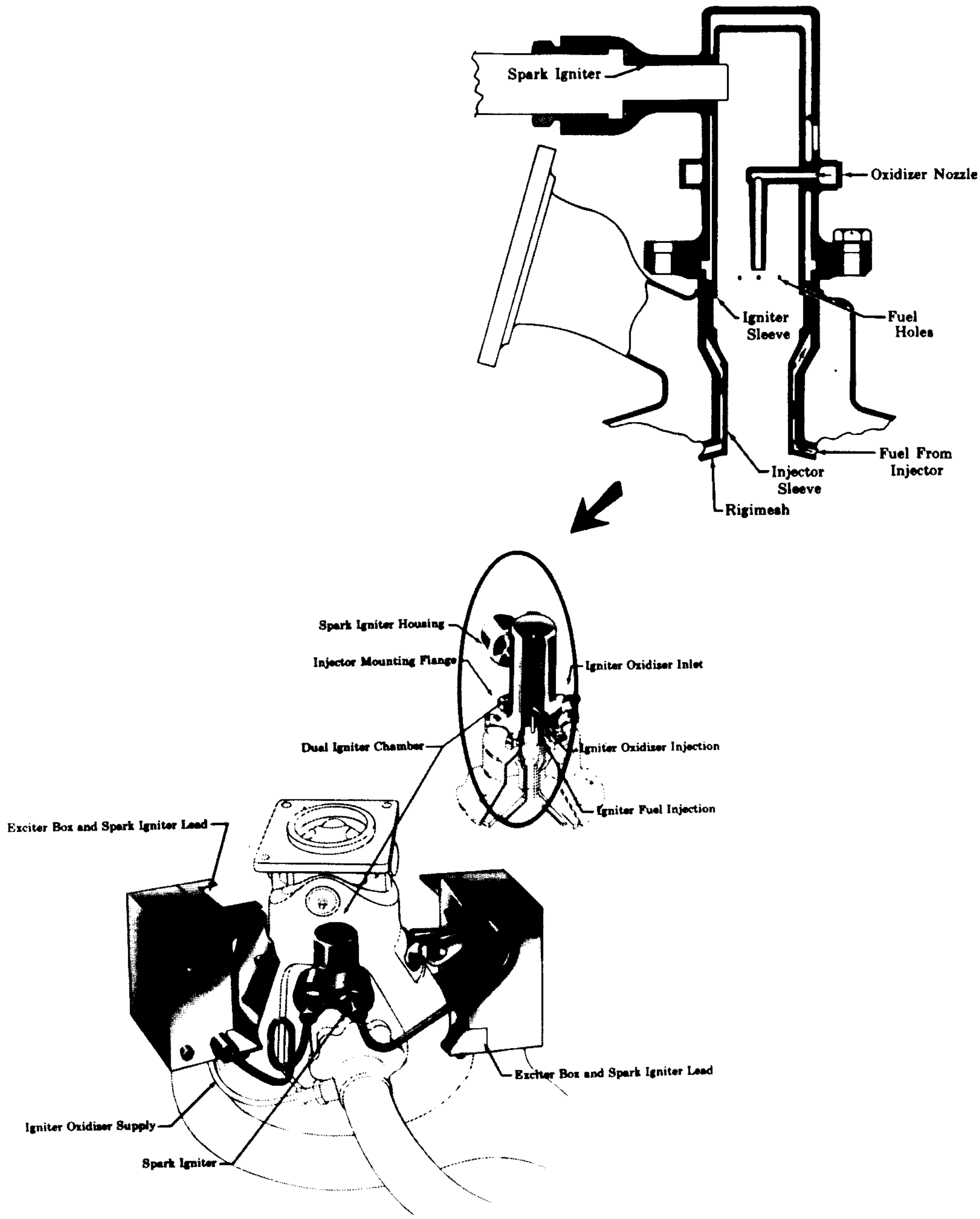

PRATT & WHITNEY AIRCRAFT
FLORIDA RESEARCH AND DEVELOPMENT CENTER
IGNITER CONDITIONS AT IGNITION
RL10A3-1 IGNITER KE42G
RUNS 595.01-621.01
RIG 20223
NO IGNITION
INTERMITTENT TORCHING
CONTINUOUS TORCHING
ARROWS INDICATE
DIRECTION OF APPROACH
TO DATA POINT CONDITIONS
IGNITER MIXTURE RATIO
IGNITER CHAMBER PRESSURE ~PSIA
3.0
2.5
2.0
1.5
1.0
0.5
200
100
80
60
40
30
20
10
8
6
4
3
2

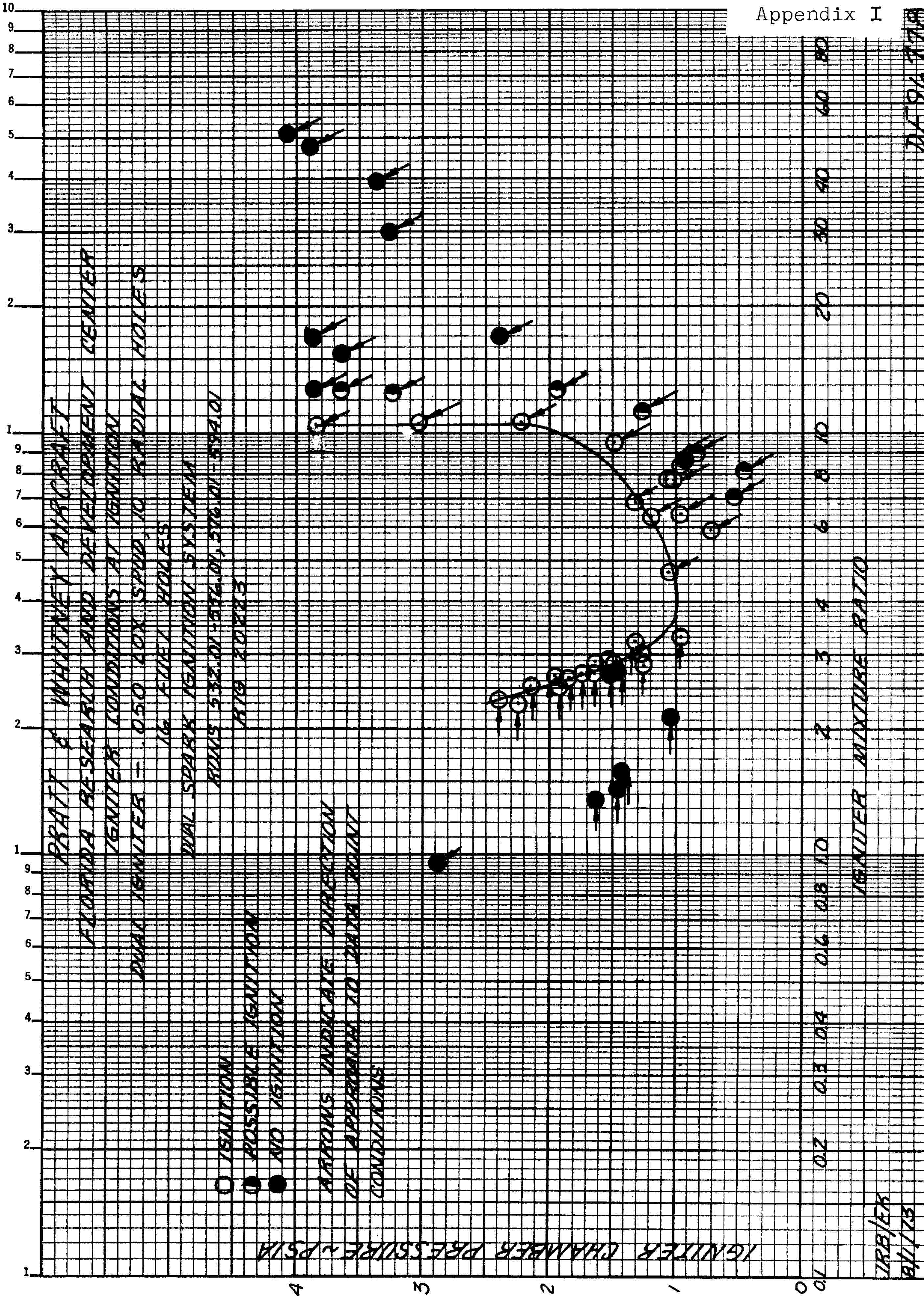
FIGURE I-4

RL10 DUAL IGNITION SYSTEM



FD 47508
700412

Figure I-5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FLORIDA RESEARCH AND DEVELOPMENT CENTER
IGNITER CONDITIONS AT IGNITION
DUAL IGNITER - .050 LOX SPUD, 10 RADIAL HOLES
16 FUEL HOLES
DUAL SPARK IGNITION SYSTEM
RUNS 532.01-556.01, 576.01-594.01
RIG 20223
IGNITION
POSSIBLE IGNITION
NO IGNITION
ARROWS INDICATE DIRECTION
OF APPROACH TO DATA POINT
CONDITIONS
IGNITER MIXTURE RATIO
IGNITER CHAMBER PRESSURE ~ PSIA
IRB/EK
8/1/73
DF 96778

FIGURE I-6

RL10A-3-3 Experimental Torch Igniter

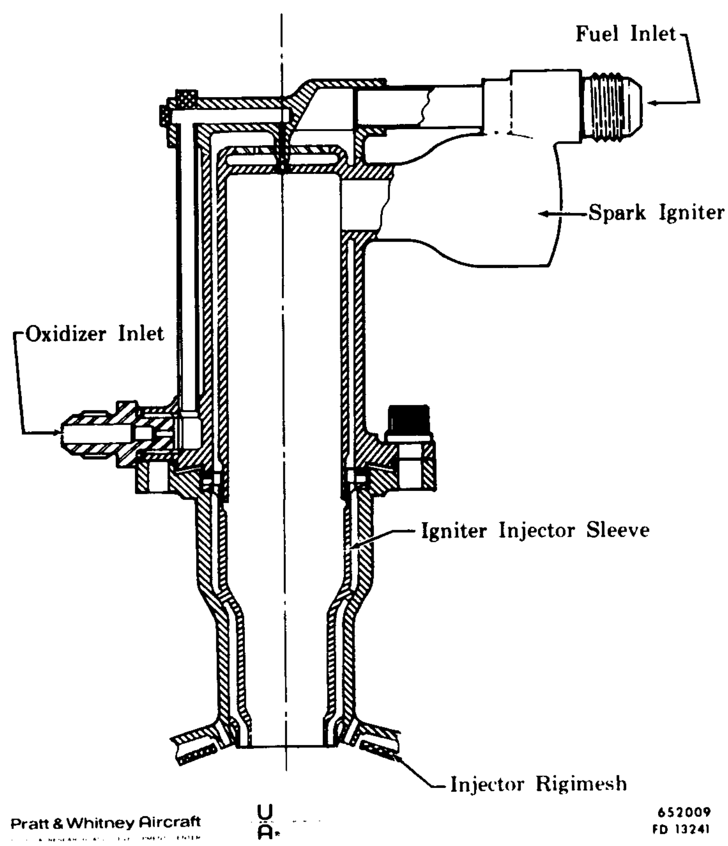


Figure I-7

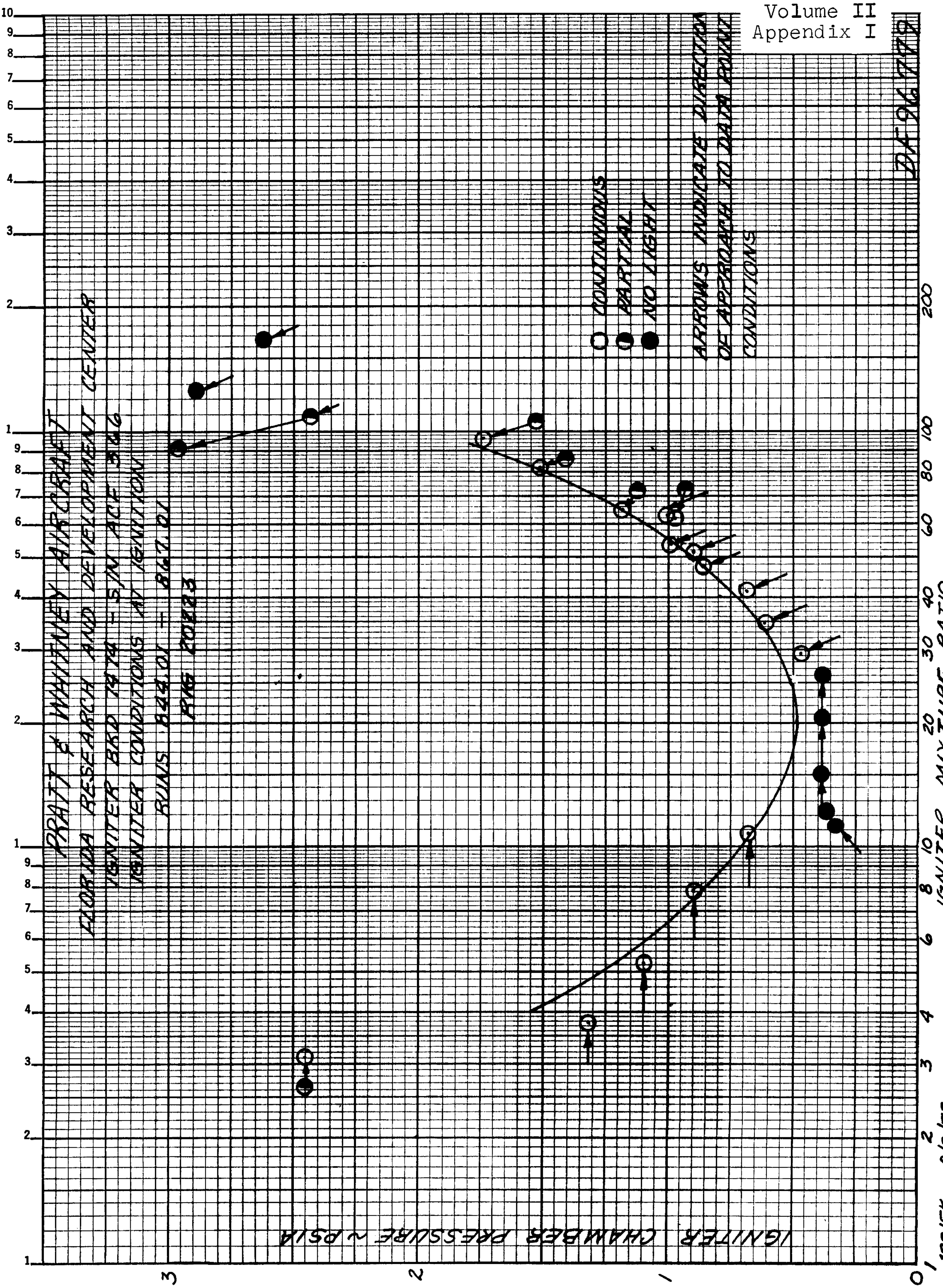

PRATT & WHITNEY AIRCRAFT
FLORIDA RESEARCH AND DEVELOPMENT CENTER
IGNITER BRD 194 - S/N ACF 366
IGNITER CONDITIONS AT IGNITION
RUNS 844.01 - 867.01
RIG 20223
CONTINUOUS
PARTIAL
NO LIGHT
ARROWS INDICATE DIRECTION OF APPROACH TO DATA POINT CONDITIONS
IGNITER MIXTURE RATIO
IGNITER CHAMBER PRESSURE ~ PSIA
DF 96779
JRB/EK 8/2/73

FIGURE I-8

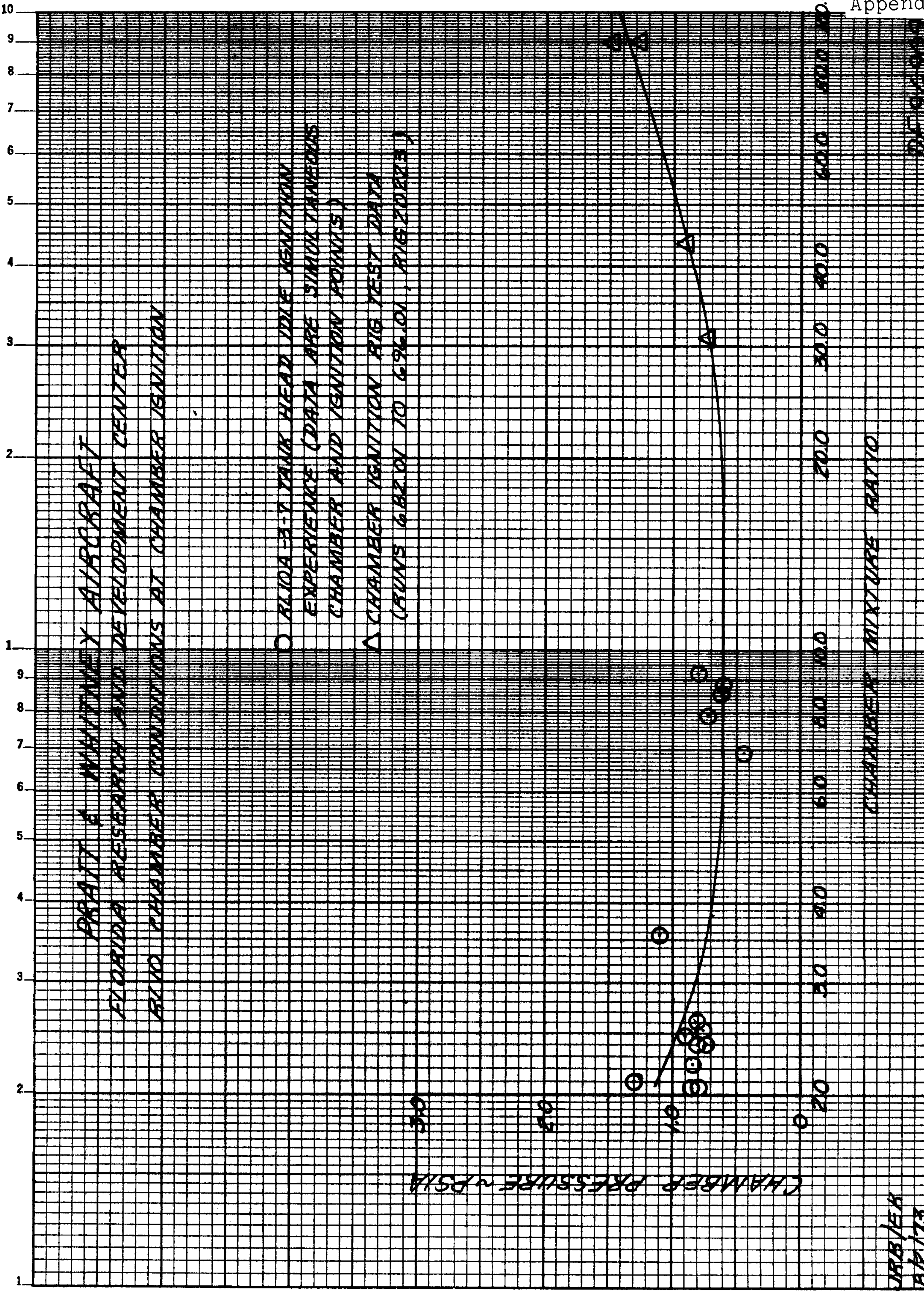

PRATT & WHITNEY AIRCRAFT
FLORIDA RESEARCH AND DEVELOPMENT CENTER
RL10 CHAMBER CONDITIONS AT CHAMBER IGNITION
○ RL10A-3-7 TANK HEAD IDLE IGNITION EXPERIENCE (DATA ARE SIMULTANEOUS CHAMBER AND IGNITION POINTS)
△ CHAMBER IGNITION RIG TEST DATA (RUNS 682.01 TO 696.01, RIG 70273)
CHAMBER MIXTURE RATIO
CHAMBER PRESSURE ~ PSIA
JRB/EK
8/2/73

FIGURE I-9

Appendix II

Engine Performance Calculations

An in-depth analysis was accomplished for the Derivative II and Category IV engines to define specific impulse characteristics. JANNAF methodology was used to define these characteristics at both design and off-design operating conditions. In this appendix, the JANNAF methodology is discussed and the results of the design point JANNAF specific impulse calculations are presented.

1. JANNAF Methodology

The JANNAF methodology used was similar to that specified in Addendum No. 1 to CPIA Publication No. 178 and Amendment No. 1 thereto. These documents outline a procedure that permits performance to be determined without use of either the JANNAF Distributed Energy Release (DER) program or the real gas JANNAF Two-Dimensional Kinetics (TDK) program. The DER program was not available during the contract period and the real gas TDK program is difficult to run and requires a large amount of computer time. Although this procedure was specifically written for the Space Shuttle Main Engine (SSME), it was sufficiently general so that application to the RL10 Derivative engines was possible.

A flow diagram of the JANNAF methodology used to calculate performance is shown in figure II-1. The first step in generating overall engine performance was to define a control volume about the engine system and establish energy and flowrate balances. Figure II-2 shows schematically the control volume and the flowrate and energy changes to the system that were considered.

Flowrates and energy levels were obtained from engine cycle balance and heat transfer calculations. The regenerative nozzle heat was assumed to come from the boundary layer and was added to the mainstream propellant enthalpy levels. The base enthalpy levels used for the mainstream propellants were the ones specified in the referenced procedures. These propellant base enthalpy levels were adjusted for the net change in energy determined by the energy balance for the control volume.

JANNAF methodology defines energy release efficiency (ηER) as a function of both mixing efficiency (ηmix) and vaporization efficiency (ηvap). For these calculations it was assumed that the mixing efficiency is 100%. Therefore, the combustion process is vaporization limited and, as such, energy release efficiency is the same as vaporization efficiency. For such cases the procedure specifies that oxidizer droplet characteristics be established using in-house methods and that the energy release efficiency be determined as a function of combustion chamber length and oxidizer droplet size. A complex analysis of injection, vaporization, and mixing characteristics is required to establish the oxidizer droplet size characteristics and the combustion system mass and mixture ratio striation characteristics. The injection and combustion process was analyzed using P&WA in-house injector and combustion system characterization programs. The analysis was conducted for the bill-of-material RL10A-3-3 injector since it is essentially the same as the injectors for the RL10 Derivative engines. The RL10A-3-3 injector was divided into five annular geometric zones. The mean mixture ratios and oxidizer vaporization

characteristics for each zone were determined from an analysis of the characteristics of the flow emerging from the individual elements. A summary of the zonal characteristics is presented in Table II-1. It shows that the overall vaporization efficiency (and therefore energy release efficiency) for the RL10A-3-3 injector is 99.4% at an overall mixture ratio of 5.0. Using the mixture ratio distribution shown it was determined that the mixture ratio striation loss was only 0.1 seconds. For the derivative engines it was assumed that comparable energy release efficiencies could be obtained at a mixture ratio of 6.0 by injector reoptimization and that striation losses could be reduced to less than 0.1 seconds.

The JANNAF One-Dimensional Kinetics (ODK) program was used to determine the nozzle kinetic losses for the specific nozzle contours of each of the three derivative engines. Nozzle divergence losses were obtained by running the Two-Dimensional Kinetics (TDK) program in an ideal gas mode.

The JANNAF Turbulent Boundary Layer (TBL) program was used to determine the boundary layer thrust loss, ΔF_{bl}. Wall temperature profiles used in the calculations were obtained from heat transfer analyses of the thrust chamber. Mainstream edge conditions for the boundary layer calculations were obtained using a P&WA Two-Dimensional Bell Nozzle Performance program run in an equilibrium mode.

Specific impulse of the hydrogen used for dump cooling was estimated from one-dimensional values of specific impulse for

heated hydrogen (~1800°R) expanded through the small nozzles (ϵ~3.5) at the end of each of the coolant passages. A specific impulse efficiency of 0.92 was assumed for the expansion process. As shown in figure II-1, these values were mass weighted with the specific impulse values for the main thrust chamber to arrive at overall engine delivered specific impulse.

The JANNAF One-Dimensional Equilibrium (ODE) program was used to establish the effect of regenerative cooling enthalpy. This program was run using both engine inlet enthalpies and the adjusted enthalpy levels described previously to determine the net effect of the enthalpy gain on performance.

2. Selection of Nozzle Contours

In order to determine specific impulse values using the JANNAF methodology, the engine configuration had to first be defined. The nozzle contours were defined using a P&WA in-house Bell Nozzle Design computer program. This program uses a two-dimensional method-of-characteristics analysis to define the nozzle characteristics. The nozzles were truncated to a minimum length contour in order to obtain the highest impulse possible for a specified engine length.

The nozzle optimization considered the effects of chamber mixture ratio and nozzle kinetic losses on the design point characteristics. The optimization was accomplished by first using assumed values of chamber pressure and mixture ratio. After the nozzle had been defined using these values, the

design point cycle program was used to predict the cycle operating characteristics. If they did not match the assumed chamber pressure and mixture ratio characteristics, an iteration was performed to find the final optimum configuration.

3. Results of JANNAF Calculations

Using the JANNAF methodology described above delivered specific impulse values were predicted for the RL10 Derivative engines. The results of the various intermediate JANNAF calculations for the design point calculations for the baseline Derivative IIA and IIB and the Category IV engines are presented in Table II-2.

Table II-1

Striation and Vaporization Efficiency Summary

RL10A-3-3 Engine

15000 lb Thrust, 5.0 O/F

Annulus Number	1	2	3	4	5	TOTAL
Area, in^2	11.4	17.8	26.0	7.9	19.25	82.35
Outer Diameter, in	3.92	6.175	8.435	9.02	10.28	
Mixture Ratio	5.0	4.98	4.95	5.45	4.76	5.06
Flow Rate, lbm/sec	5.1	7.66	10.98	7.39	2.52	33.65
Flow per Unit Area, $lbm/sec/in^2$	.447	.431	.423	.935	.131	
Vaporization Efficiency, %	100.	100.	100.	98.0	98.0	99.41

TABLE II-2

Summary of JANNAF Methodology Results
RL10 Derivative Engines

	Derivative IIA and IIB	Category IV
Nozzle Area Ratio	263	401
Chamber Pressure, psia	400	915
Engine Overall Mixture Ratio	6.0	6.0
Chamber Mixture Ratio	6.4	6.4
Chamber Total Propellant Flow, lb/sec	32.44	31.53
Ivac' (Inlet Conditions) at chamber O/F(ODE), sec	479.3	484.9
Δ h Regen, BTU/lb H2	1562	1920
Ivac' (with Δ h) at chamber O/F(ODE), sec	487.3	494.8
Ivac' (with Kinetic loss)(ODK), sec	479.5	490.3
Divergence Efficiency (TDK), %	98.63	98.96
Boundary Layer Thrust Loss (TBL), ΔF_{BL}, lbs	289	385
Energy Release Efficiency, %	99.41	99.41
Striation Loss, sec	<0.1	<0.1
Overboard Leakage Loss, sec	<0.1	<0.1
Ivac' (Dump Nozzle), sec	475.0	475.0
Impulse Efficiency of Dump Nozzle, %	92.	92.
Ivac Delivered (JANNAF), sec	461.0	470.0

JANNAF PERFORMANCE METHODOLOGY FLOW CHART

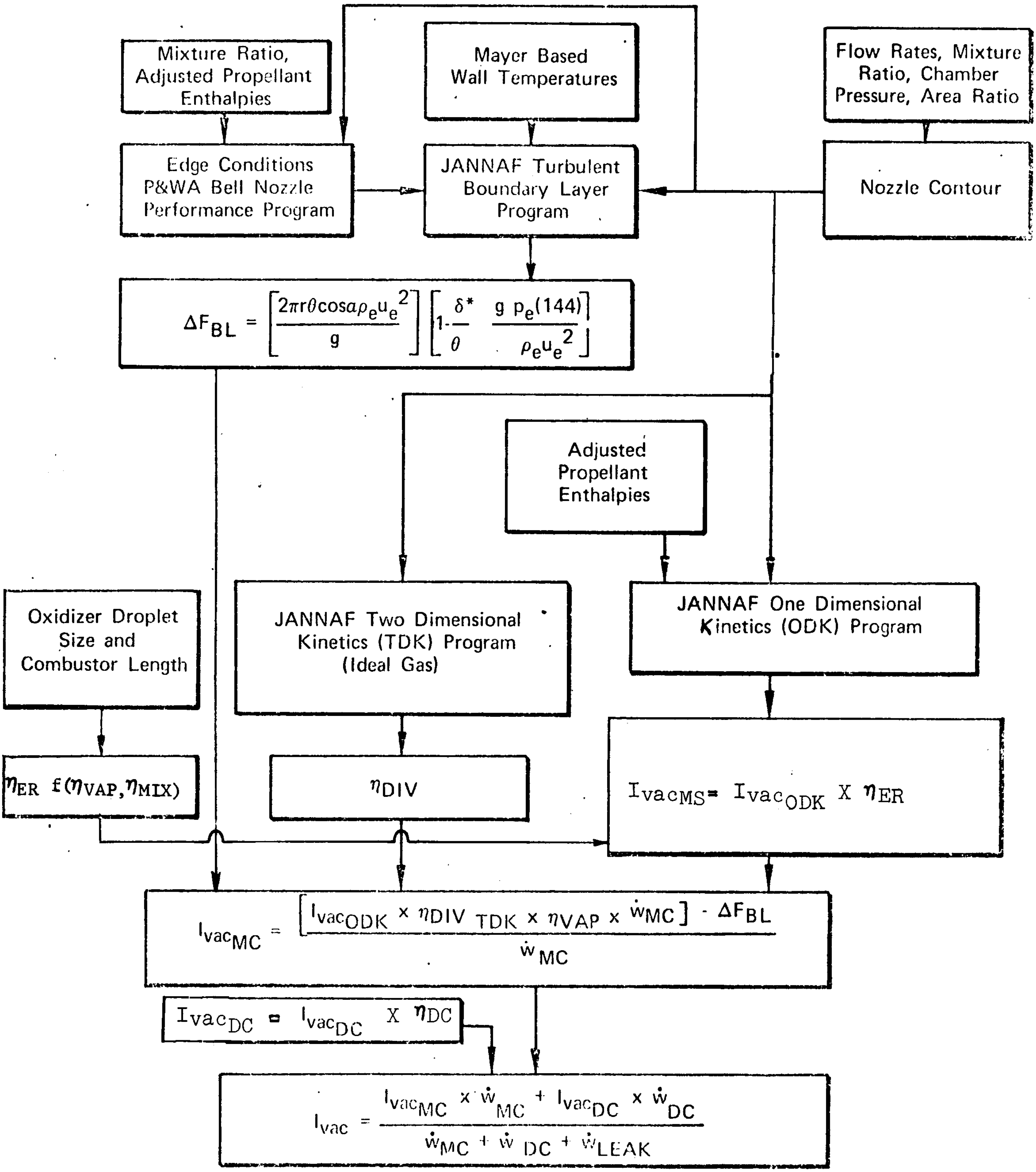


Figure II-1

CONTROL VOLUME SCHEMATIC - ENERGY AND FLOW BALANCE

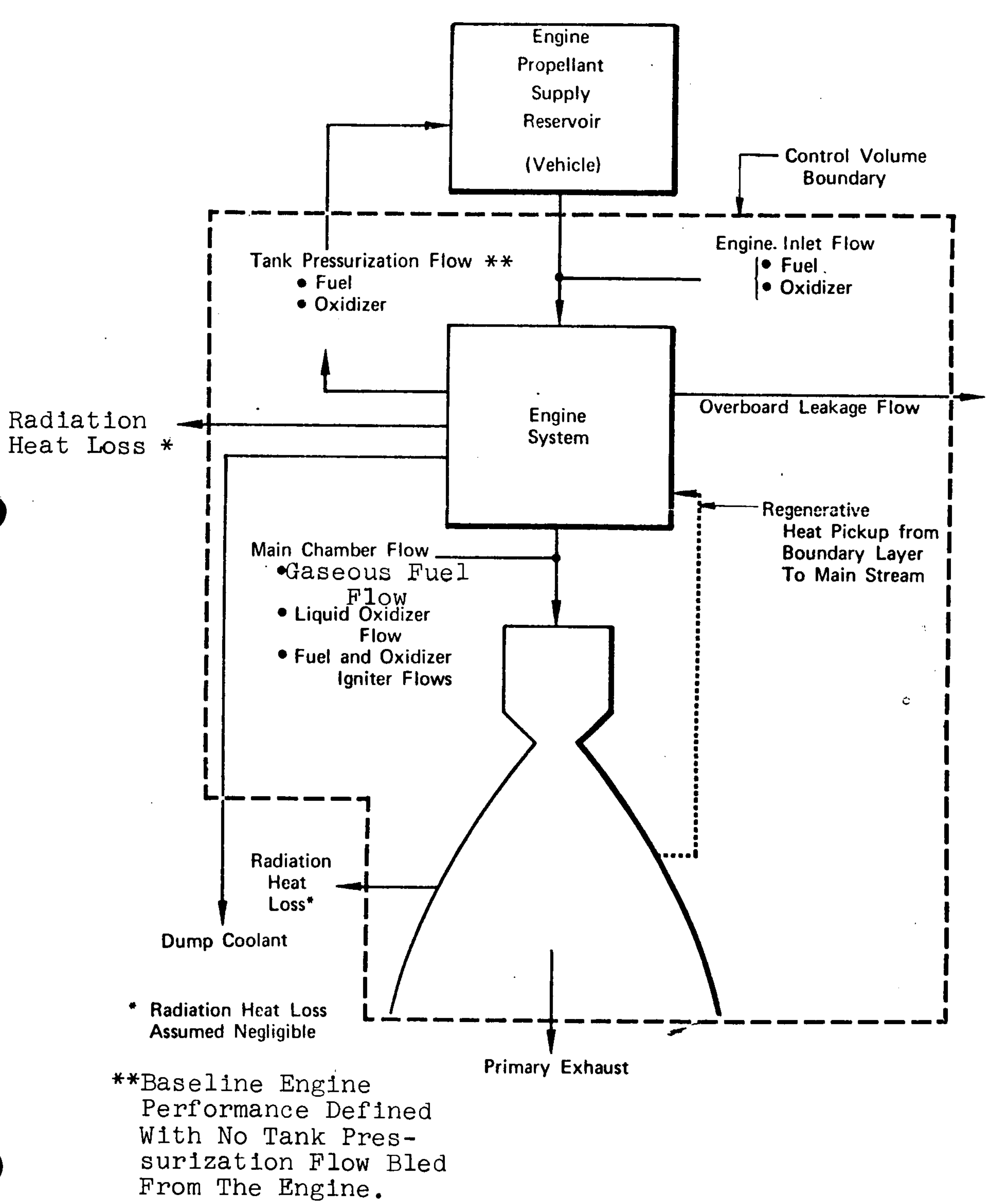


Figure II-2

Appendix III

Definition of Engine Transient Characteristics

Two transient computer simulation programs were used to define the transient characteristics and control system requirements for the Derivative IIA and IIB and Category IV engines. One of these program was used to simulate turbopump cooldown for all of the engines (THI transients) and the acceleration and deceleration transients for the Derivative IIA and IIB engines. The other program was used to simulate the acceleration and deceleration transients for the Category IV engine. Options are available in the programs to select the engine configuration, the inlet conditions, the mode of operation and the type of transient to be run. In addition, the programs have the capability of operating in a steady state mode and generating the valve areas required for any desired thrust and mixture ratio level.

To reduce computer costs, options were incorporated in the programs to allow each of the different kinds of transients to be run independently of each other or in series with another transient, i.e. a THI transient and a THI to maneuvering thrust transient can be but they do not have to be completed before a maneuvering thrust to full thrust transient can be simulated. When they are run independently, the transients are started from a steady state mode and it is assumed that the engine has stabilized at that particular thrust and mixture ratio prior to the transient being initiated. The programs also have a restart capability

which allows a transient or THI run to be stopped and restarted at any time during the transient without losing the effects of the transient dynamics.

Tank Head Idle simulations can be made for any of the engine configurations with different propellant conditions (gas, liquid or two-phase), different initial ambient temperatures and different initial suction line temperatures. Vehicle/engine interactions can be included for both the THI cooldown and the engine transients by mating vehicle inlet line and propellant tank simulations with the engine simulations.

The methods used to simulate the components in the transient simulations are similar to those used in the steady state cycle program discussed in Appendix IV. The major differences in the programs are the dynamics included in the transient programs and additional routines required for THI cooldown.

1. Acceleration and Deceleration Transient Simulations

Figure III-1 is a simplified flow schematic that shows the more important calculations and convergence loops used to simulate a Derivative IIA engine during acceleration or deceleration transients. Except for the oxidizer low speed inducer portion of the simulation, this flow schematic is also representative of the simulation for the Derivative IIB engine. The Category IV engine simulation is also similar; however, is has a fuel low speed inducer simulation located upstream of the fuel pump and the single turbine simulation is replaced with simulations for the two turbines in series. Dynamics are one of the main considerations.

in this program and a brief discussion of the dynamics used is included later in this Appendix.

2. Tank Head Idle Cooldown Simulations

Figure II-2 is a flow schematic which shows how the Derivative IIA engine is simulated during a tank head idle cooldown transient. The Derivative IIA and Category IV engine simulations are similar except for the low speed inducer and turbine routines. Since the effects of fluid dynamics on these transients are insignificant compared to the effects of the thermal dynamics, steady state flow is assumed to exist at each time increment during the THI transients and a Newton-Raphson rapid convergence technique is used to balance the simulation at each increment. The independent variables used to balance the programs are fuel flow, pressure at the inlet of the primary nozzle heat exchanger and chamber pressure, and the dependent variables are fuel flow, primary nozzle heat exchanger exit pressure and combustion chamber inlet and outlet flows. Fuel flow, inlet pressure to the heat exchanger and chamber pressure are varied at each time increment until the assumed fuel flow at the heat exchanger inlet equals the flow calculated through the second stage of the fuel pump, the pressure calculated at the exit of the primary nozzle heat exchanger equals the pressure calculated at the inlet of the turbine bypass valve, and the total flowrate entering the combustion chamber equals the flowrate calculated at the throat of the chamber.

3. Method for Simulating Engine Dynamics

Dynamic performance characteristics are determined by numerically integrating time varying differential equations. This is accomplished by calculating the differentials from known variables such as pressures, flows, speeds, etc, multiplying the differentials by the time increment (DT) selected for the program, and adding the result to the last calculated value of the parameter being integrated. The technique of numerical integration is shown by the following example where flow rates through a known control volume are integrated to obtain the pressure within the volume.

The integral equation is defined by

$$P = \int \sum W dt$$

where P is pressure

and $\sum W$ is summation of flow rates crossing volume boundaries

Expressing the equation in finite difference form

$$P_n = P_{n-1} + \Delta P$$

where P_n is pressure at time = n

and P_{n-1} is pressure at time = n-1

Using numerical integration

$$\Delta P = \sum W \cdot DT$$

where DT = integration time increment

This method of numerical integration is used to define the dynamic behavior of the engines. The dynamic elements of the engines that have been simulated include:

1. Acceleration of oxidizer and fuel turbopumps
2. Thermal dynamics of all turbopumps (cooldown)
3. Thermal dynamics of the inlet propellant feed lines (cooldown)
4. Thermal dynamics of the primary nozzle heat exchanger and the Gox heat exchanger
5. Fluid dynamics of the heat exchanger and main chamber

The integration time increment (DT) is an input variable. The DT value normally used provides a compromise between simulation accuracy and the amount of computer time required to run the simulation. The DT varies depending upon the operating mode of the simulation.

A simulation of tank head idle requires much more computer time than a simulation of a turbopump acceleration to full thrust. During a cooldown, fluid dynamics are of secondary importance compared to cooldown thermal dynamics. This permits large time increments (1.0 second) to be used for THI to minimize computer time. To accomodate the large DT and prevent "mathematical instabilities" steady state flow is assumed during the cooldown. Dynamic heat transfer equations are used to simulate the component cooldowns, and flowrates and pressure are calculated as a function of the exit temperatures, pressures, and densities.

At the conclusion of cooldown when the turbopumps are started, the DT is reduced to 0.01 seconds to permit the turbopump acceleration dynamics to be considered. At the end of pumped idle (maneuvering thrust) the DT is reduced further to 0.001 seconds.

During the acceleration to full thrust and the deceleration to pumped idle the turbopump and fluid dynamics become very significant.

4. Method for Simulating Engine Cooldown

Special calculations are required to simulate the transient thermal conditioning of the inlet lines and engines. These routines were developed for the RL10 engine and they were checked out using RL10 test data generated under simulated space conditions at the NASA Plumbrook facility.

For this simulation a quasi-steady state solution of the conventional lumped mode thermal energy transfer and storage equations is made. Conduction, heat storage, phase change, free and forced convection capability, plus radiation boundary conditions are all considered. Temperature variable solid and fluid properties are used.

The engine lines, housings, valves, etc. are transformed into equivalent rods and cylinders. The thermal model then performs a one-dimensional, quasi-steady state heat transfer analysis of the engine system. Each component of the engine may be subdivided into several such rod and cylinder combinations and they may be linked together in different flow and conduction path patterns. A simulation of a typical engine fuel pump is shown in Figure III-3.

A typical engine cooldown calculation is shown in the following example. In this case, the engine system is made up of components (rods and cylinders) at some initial temp-

erature and it is subjected to known external heat loads and fluid inlet conditions. The system is evaluated over a small time increment and an energy balance is made for the first rod/cylinder combination. The change in energy stored in the cylinder is determined by calculating the heat removed from the cylinder by the convective cooldown process of the coolant flow and subtracting the heat added to the system from external heat load sources. The energy change of the rod is also determined by defining the heat removed by the convection process of the coolant. The energy increase of the coolant then becomes the sum of the heat energies removed from both the rod and cylinder surfaces. This energy is added to the fluid in the form of enthalpy and velocity increases which are determined by continuity and energy conservation equations. The properties of the coolant leaving the first component become the inlet conditions for the next component and these calculations are repeated for each component in the system. The basic equations used to calculate the thermal characteristics of the components during THI are:

1. $Q1 = h_1 A_1 (\overline{T}_{W1} - \overline{T})\, dt$
2. $Q2 = h_2 A_2 (\overline{T}_{W2} - \overline{T})\, dt$
3. $Q_{TOTAL} = Q1 + Q2$
4. $H_2 = H_1 + \frac{Q_{TOTAL}}{Wdt} + \left(\frac{V_1^2}{2} - \frac{V^2{}_2}{2}\right) \times 47205$
5. $\rho_1 V_1 = \rho_2 V_2$

where Q = heat transferred, BTU

A = area, ft^2

h = heat transfer coefficient, BTU/sec - ft^2 - ^oR

$\bar{T}$ = Temperature (Average), ^oR

dt = delta time increment, sec

H = fluid enthalpy, BTU/lbm

V = fluid velocity, ft/sec

ρ = fluid density, lb/ft^3

and subscripts

1 = upstream condition or outer component (cylinder)

2 = downstream condition or inner component (rod)

w = wall condition

The energy removed from each component has now created a system unbalance in the form of a temperature gradient between each rod and cylinder and their adjacent components. This unbalance initiates a conduction process which alters the distribution of the remaining energy in the system and reduces the temperature gradient between the various components. This transfer of conduction energy is determined by solving the second law of thermodynamics. The solution obtained at the end of one time increment provides the starting conditions for the next time increment and the analysis is continued until the temperatures of critical components (pump housings and impellers) reach desired levels.

5. Baseline Engine Transient Characteristics

Transient characteristics obtained for each of the baseline engines are included in this appendix. Numerous engine parameters were determined from the simulations of these transients. The parameters that best defined engine operating characteristics

were plotted and they are included in Figures III-4 through III-14. The transients included are as follows:

a. Tank Head Idle Transients

   (1) Derivative IIA, Figure III-4

   (2) Derivative IIB, Figure III-5

   (3) Category IV, Figure III-6

b. Derivative IIA & IIB Start and Deceleration Transients

   (1) Start Transients

      (a) THI to maneuvering thrust, Figure III-7

      (b) Maneuvering thrust to full thrust, Figure III-8

   (2) Deceleration Transients

      (a) Full thrust to maneuvering thrust, Figure III-9

      (b) Maneuvering thrust to THI, Figure III-10

c. Category IV Start and Deceleration Transients

   (1) Start Transients

      (a) THI to maneuvering thrust, Figure III-11

      (b) Maneuvering thrust to full thrust, Figure III-12

   (2) Deceleration Transients

      (a) Full thrust to maneuvering thrust, Figure III-13

      (b) Maneuvering thrust to THI, Figure III-14

TRANSIENT SIMULATION FLOW SCHEMATIC DERIVATIVE IIA ENGINE

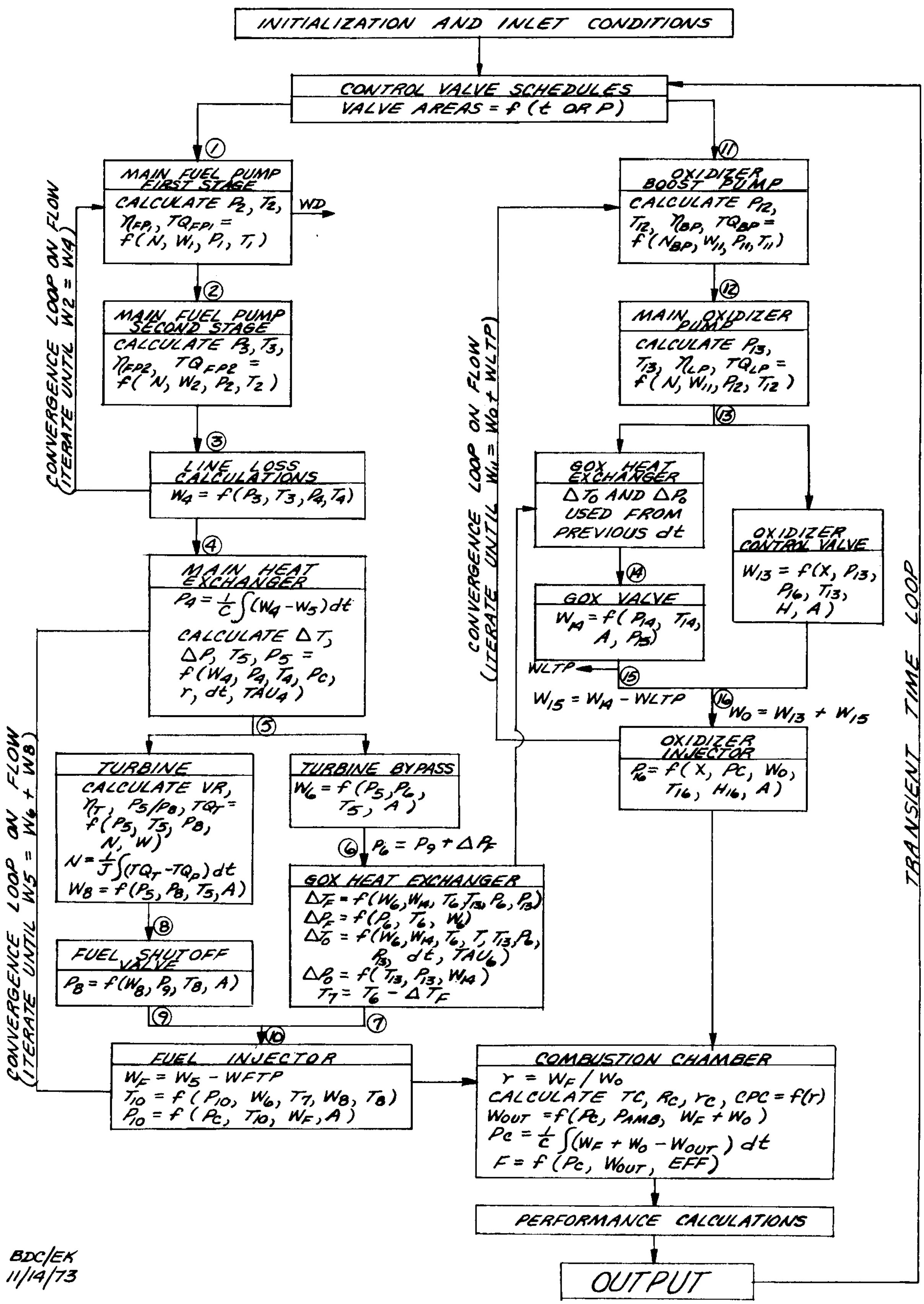


FIGURE III-1

FLOWPATH OF DERIVATIVE IIA ENGINE DURING TANK HEAD IDLE TRANSIENT

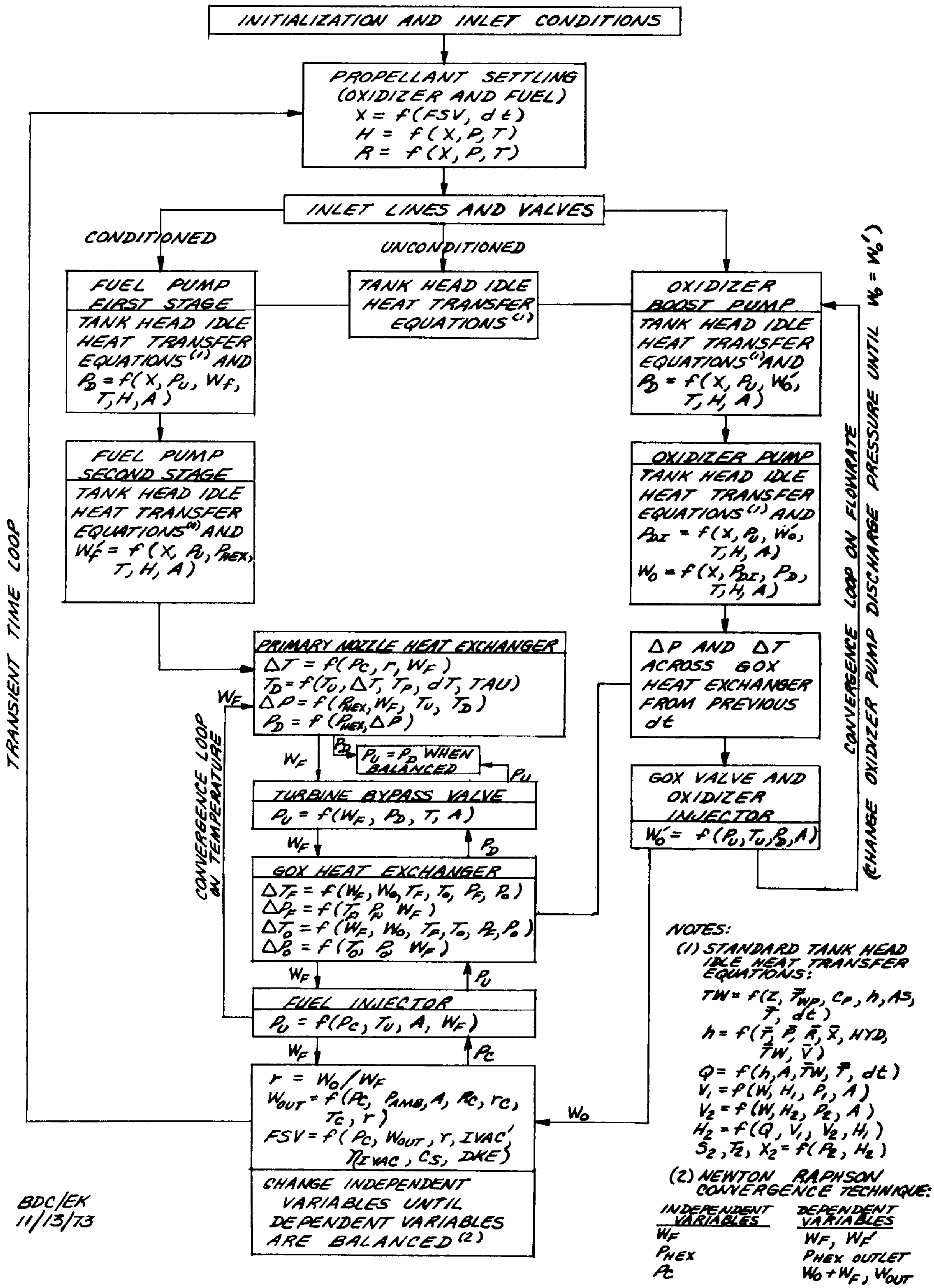


FIGURE III-2

Nomenclature for Figures III-1 and III-2:

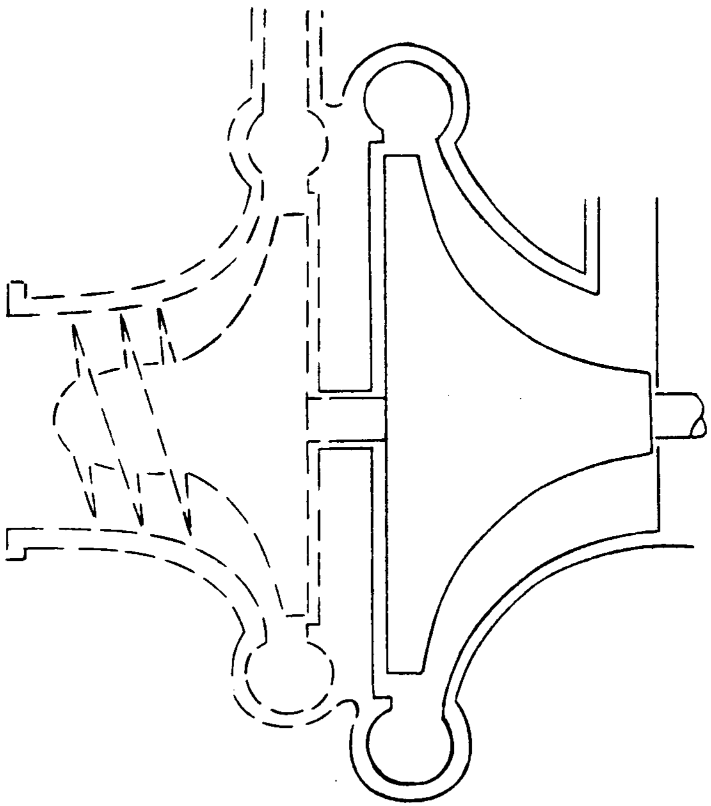
A	Area, $inches^2$
AS	Surface Area, $inches^2$
C	Capacitance
C_p	Specific Heat Capacity, BTU/lb_m - ^oR
Cs	Nozzle Boundary Layer Loss and Divergence Loss
DKE	Nozzle Kinetic Loss
dt	Time increment, seconds
EFF	Efficiency Terms Cs, DKE, ηc^*
FSV	Thrust, lb_f
H	Enthalpy, BTU/lb_m
HYD	Hydraulic Diameter, inches
h	Heat Transfer Coefficient, BTU/hr - ft^2 - ^oR
Ivac'	Ideal Vacuum Specific Impulse, sec.
J	Turbopump Polar Moment of Inertia, ft-lb-sec^2
N	Turbopump Speed, RPM
P	Pressure, psia
Pamb	Ambient Pressure, psia
Pc	Combustion chamber pressure, psia
Q	Heat transferred, BTU
R	Density, lbm/ft^3
Rc	Gas Constant, ft-lbs/^oR-lbm
r	Mixture ratio
S	Entropy, BTU/lb_m-^oR
T	Temperature, ^oR
TQ	Torque, ft-lbs

TW	Wall temperature, ^{o}R
t	time, seconds
TAU	Transient response time constant, sec
V	Velocity, ft/sec
VR	Turbine Velocity Ratio
W	Flowrate, lbm/sec
W_f'	Fuel flowrate calculated at second stage discharge, lbm/sec
W_o'	Oxidizer flowrate calculated through oxidizer injector, lbm/sec
WD	Dump coolant flowrate, lbm/sec
WFTP	Fuel tank pressurization flowrate, lbm/sec
WLTP	Oxidizer tank pressurization flowrate, lbm/sec
X	Propellant Quality
Z	Component (Impeller, pump housing, etc.) mass, lbm
η	Efficiency (pump or turbine)
ηIvac	Vacuum impulse efficiency
γ	Specific heat ratio
ΔP	Pressure loss, psid
ΔT	Temperature rise, ^{o}R

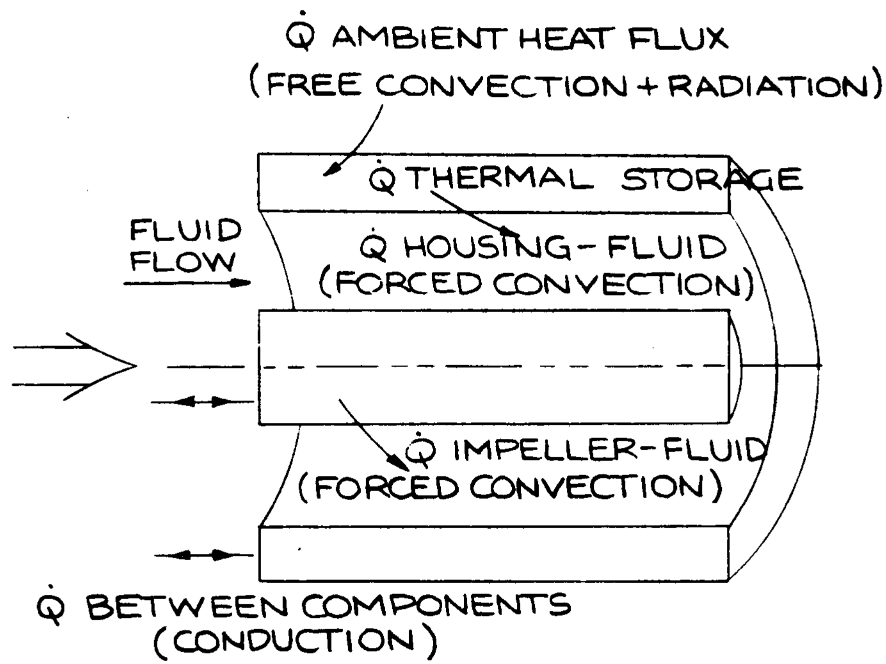
Subscript	Description
1,2,...16	Station locations
BP	boost pump
C	Combustion chamber
D	Discharge
f	Fuel propellant
FP_1	Fuel pump, 1st stage

FP_2	Fuel pump, 2nd stage
O	Oxidizer propellant
P	previous value
T	Turbine
U	Upstream
	Average

HEAT TRANSFER MODEL SIMULATES THERMAL CONDITIONS OF COMPONENTS AND FLUIDS



FUEL PUMP



AXISYMMETRIC THERMAL MODEL ANALOG

11-13-73

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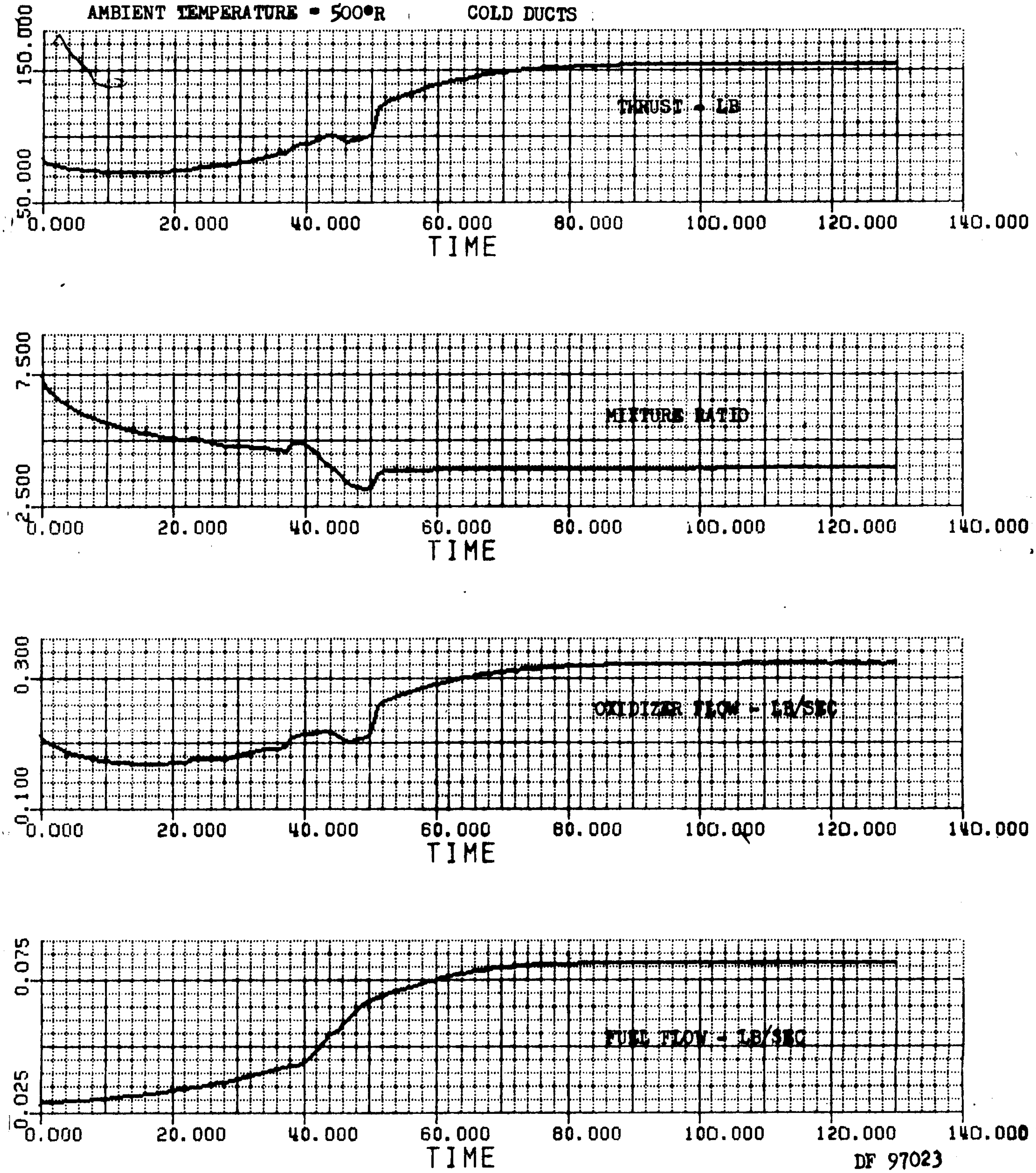
FIGURE III-3

PRATT & WHITNEY AIRCRAFT
SIMULATED COOLDOWN TRANSIENT
DERIVATIVE IIA ENGINE

16 PSIA SATURATED VAPOR AT INLETS DURING START
AMBIENT TEMPERATURE = 500°R COLD DUCTS



DF 97023
SHEET 1 OF 7
FIGURE III-4

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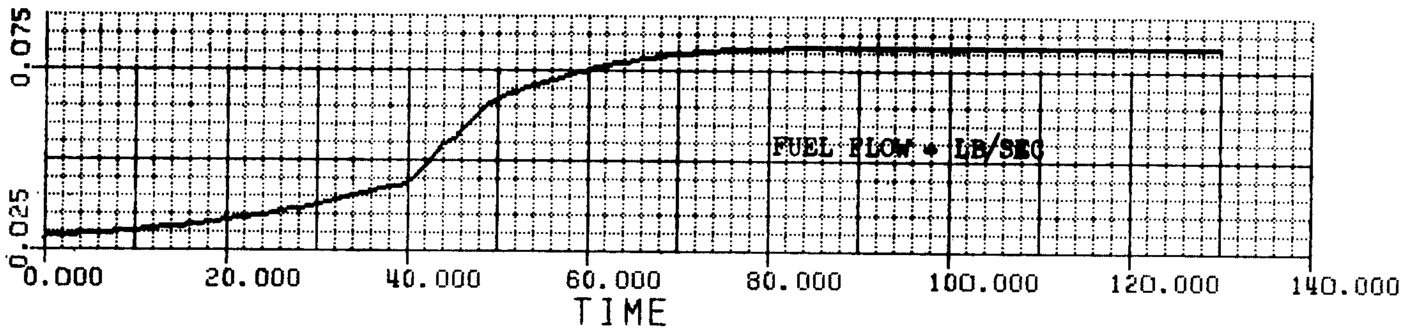

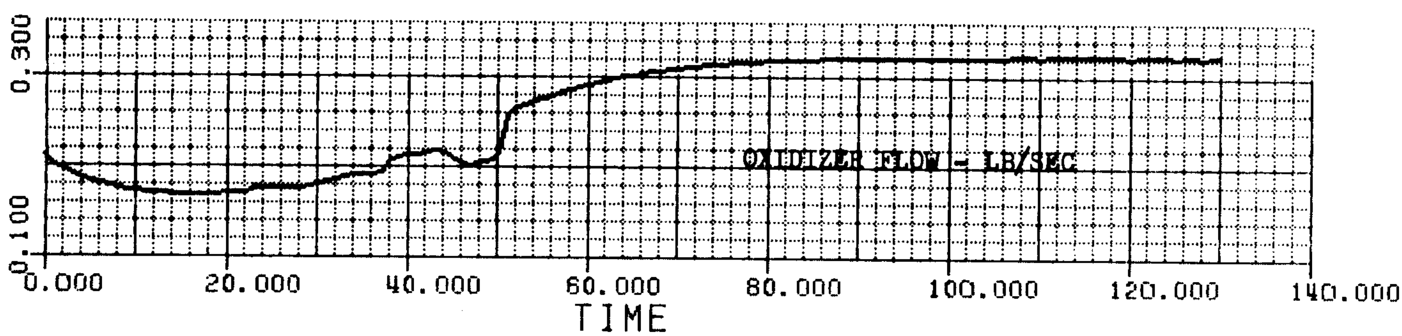

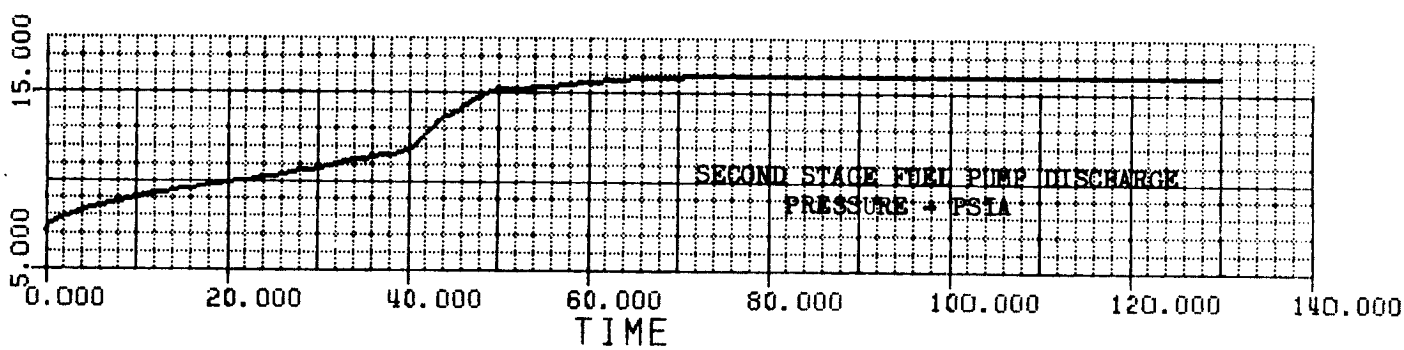

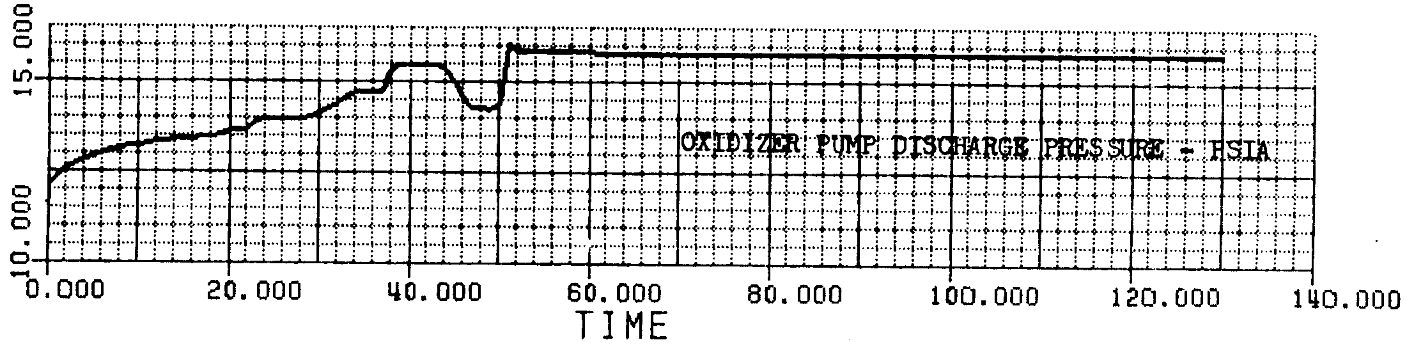

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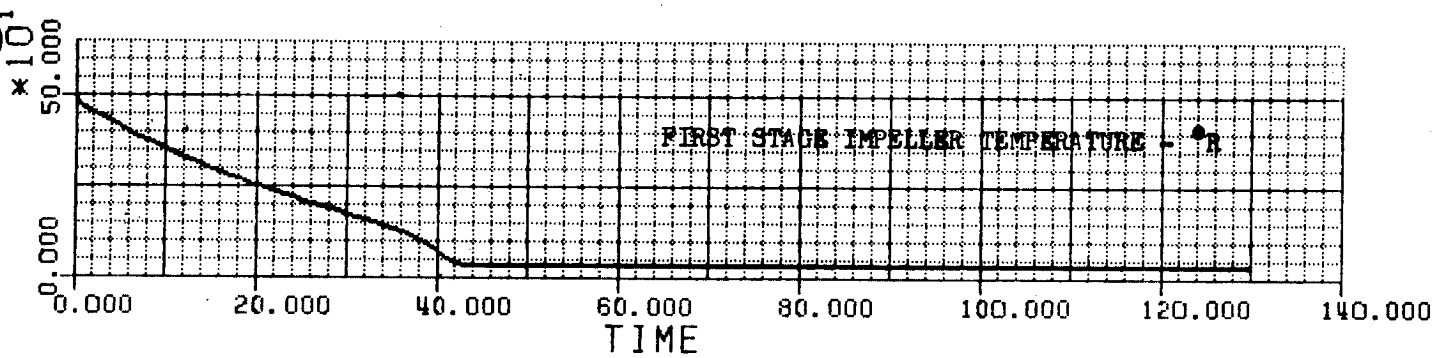
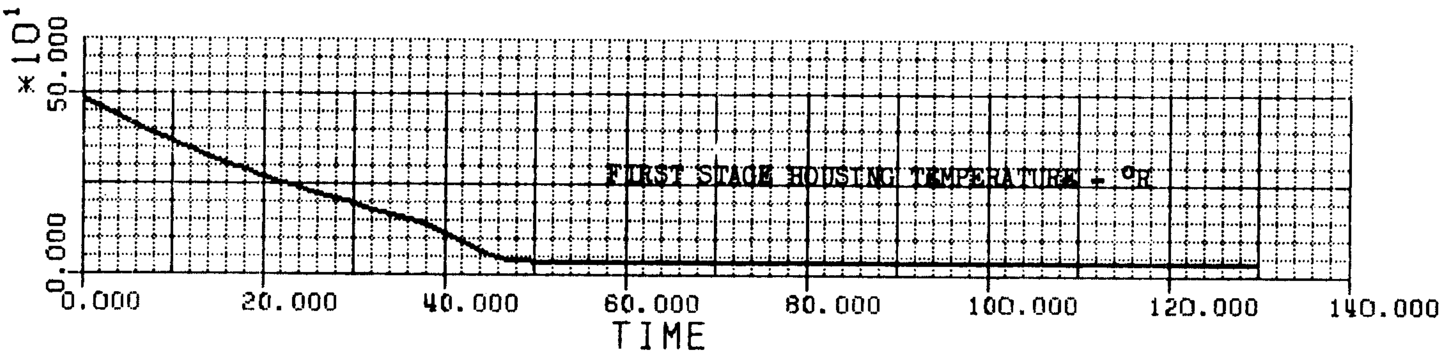
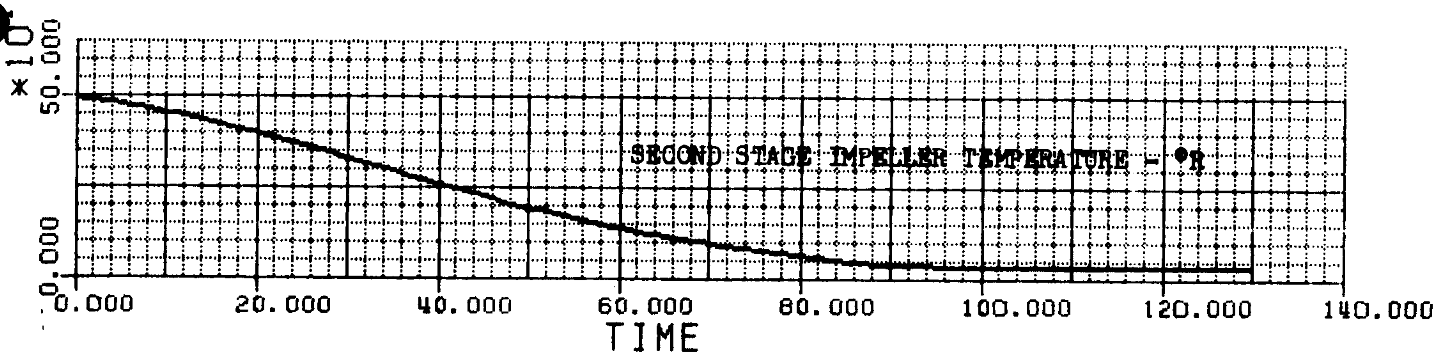
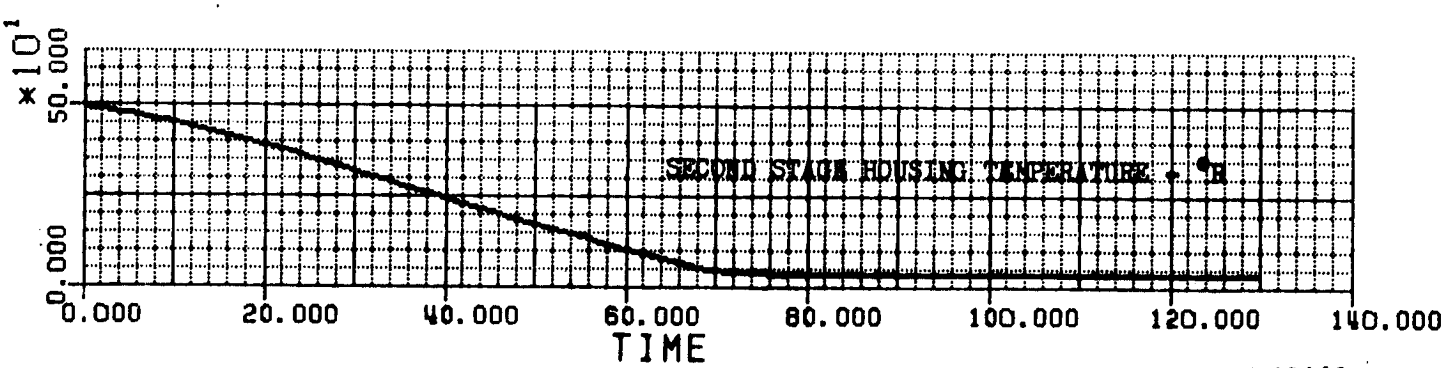
DF 97023
SHEET 2 OF 7
FIGURE III-4

FUEL PUMP









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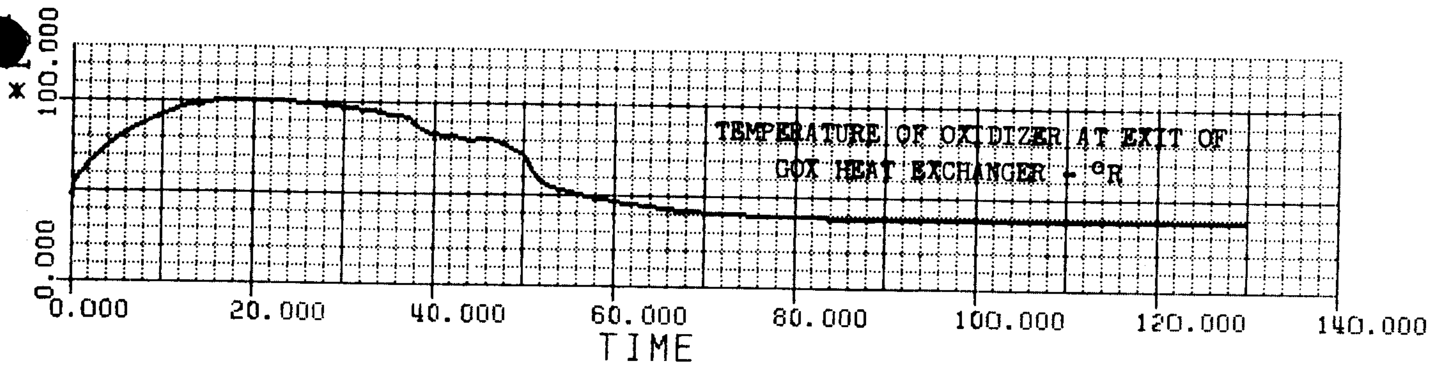
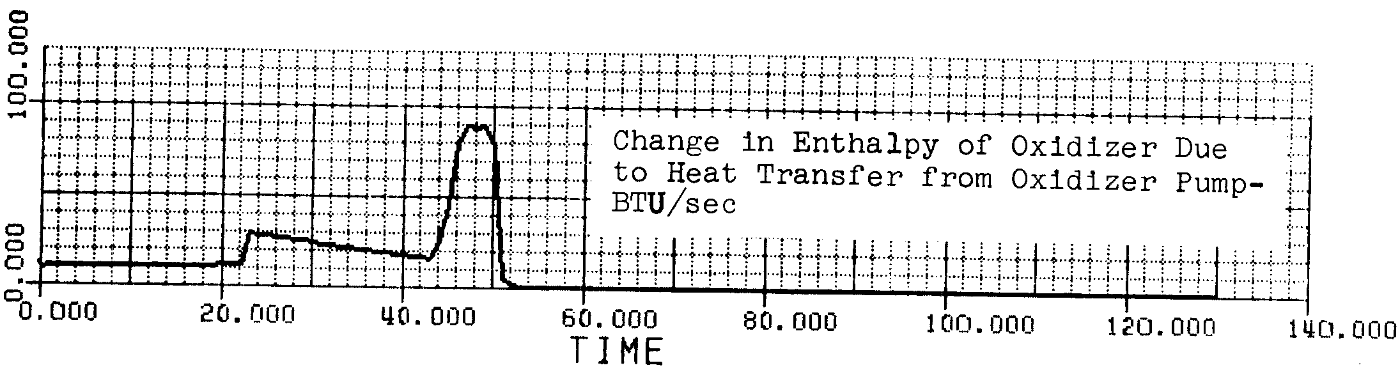
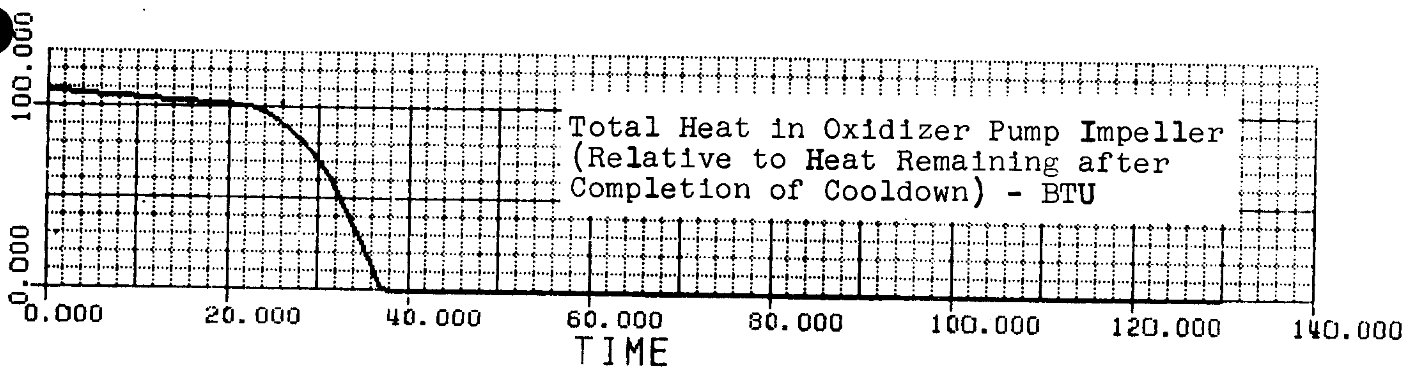
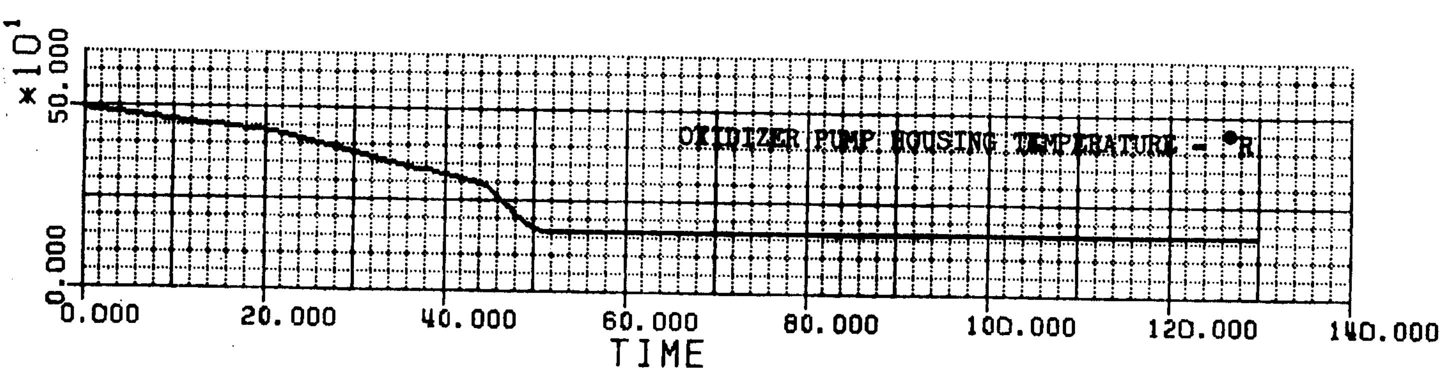
DF 97023
SHEET 3 OF 7
FIGURE III-4









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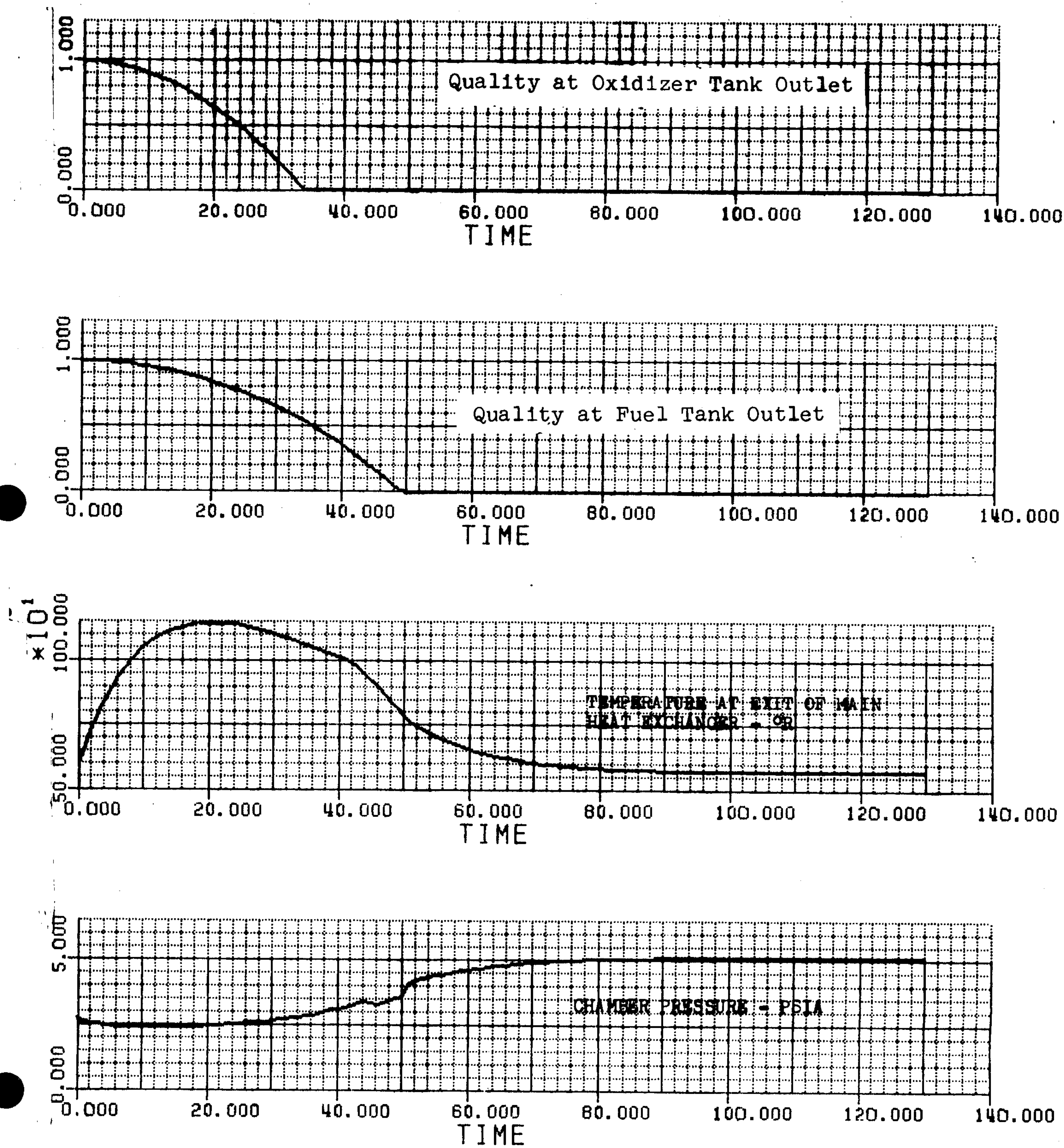
DF 97023
SHEET 4 OF 7
FIGURE III-4



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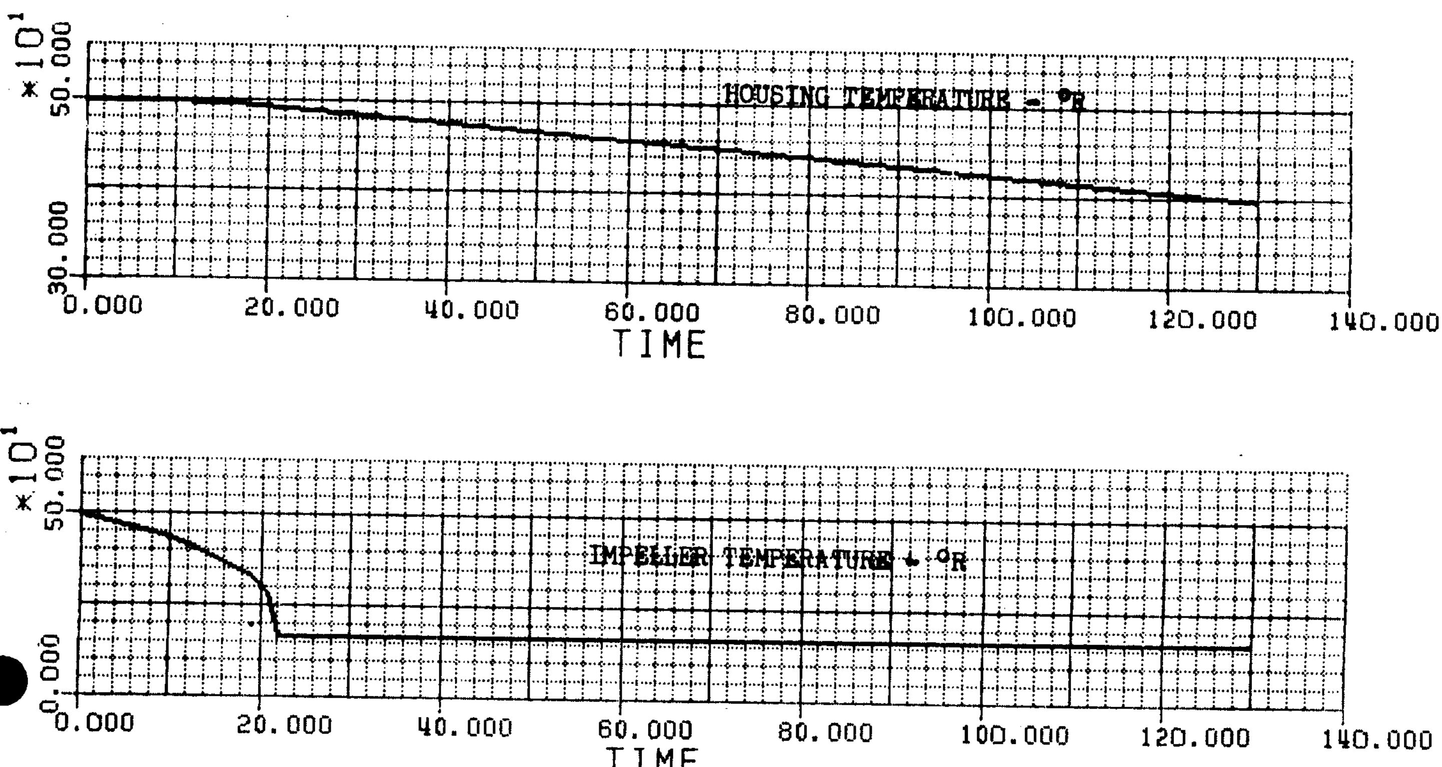
DF 97023
SHEET 5 OF 7
FIGURE III-4

OXIDIZER BOOST PUMP



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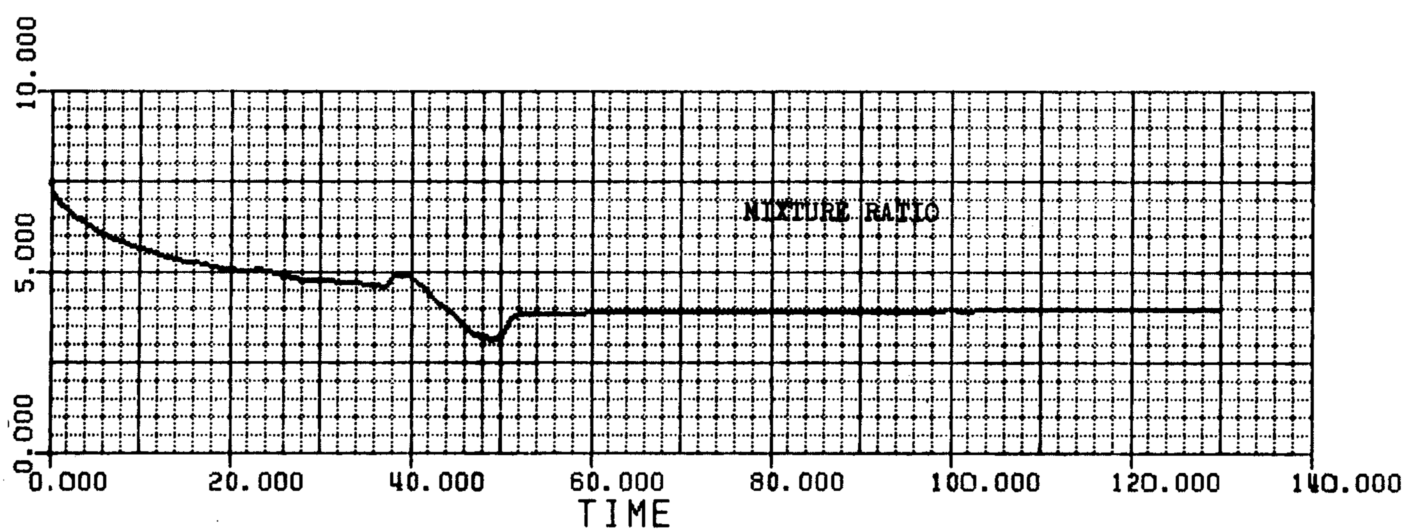
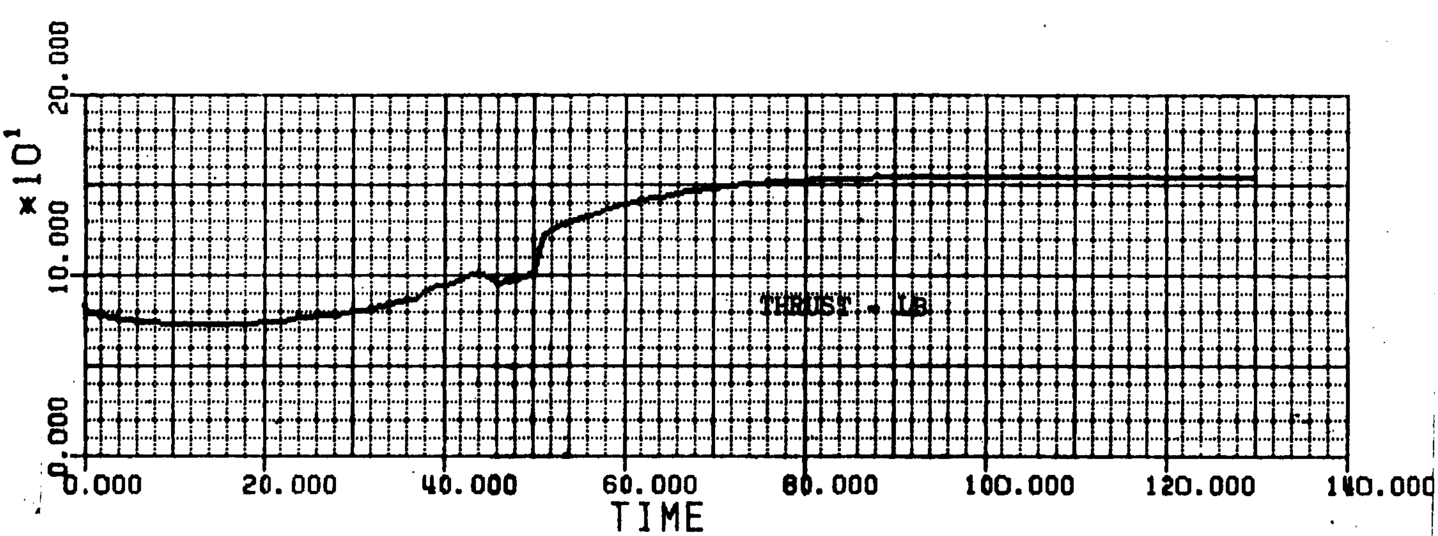
DF 97023
SHEET 6 OF 7
FIGURE III-4





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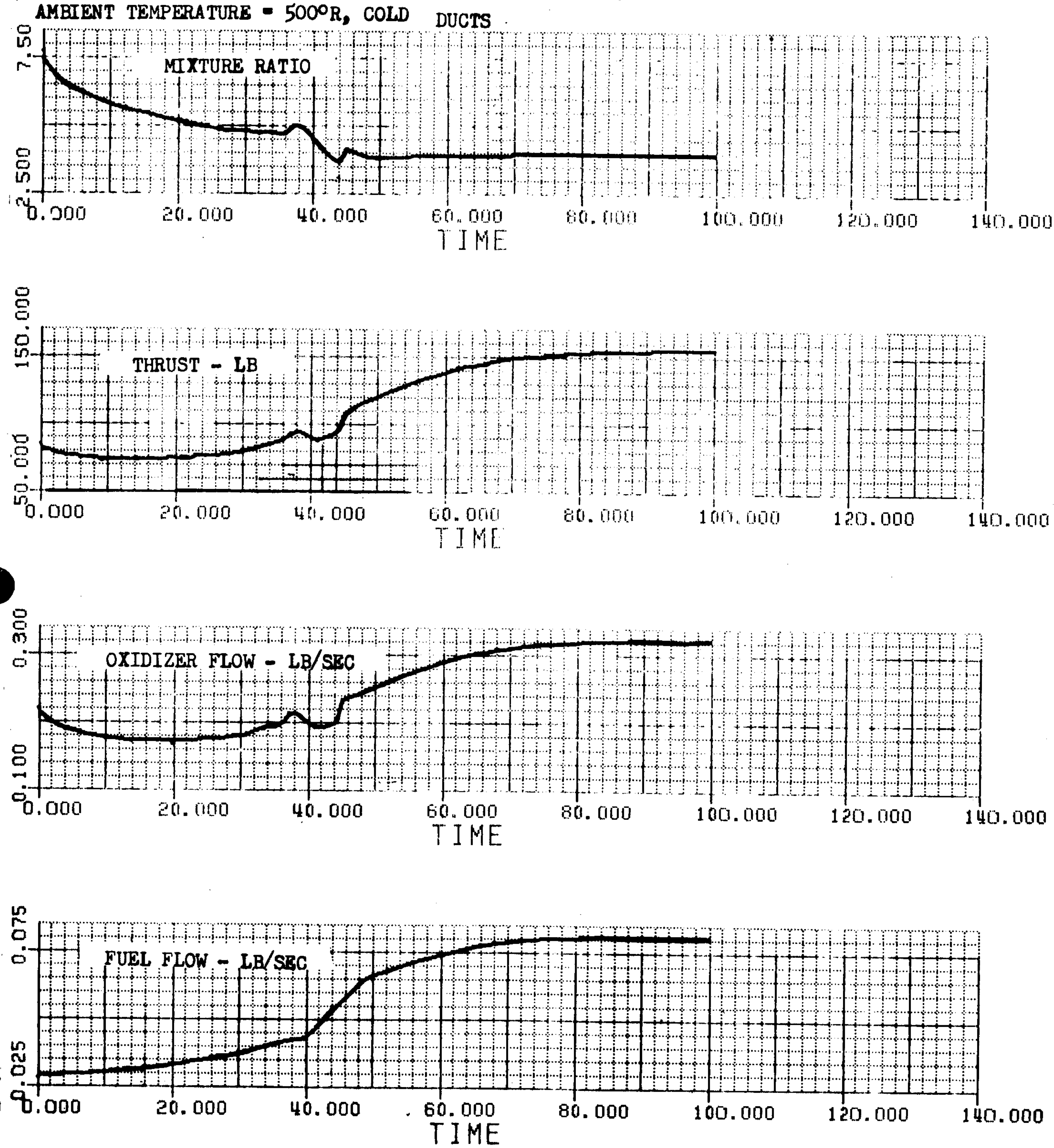
DF 97023
SHEET 7 OF 7
FIGURE III-4

PRATT & WHITNEY AIRCRAFT
SIMULATED COOLDOWN TRANSIENT
DERIVATIVE IIB ENGINE

INLET PRESSURES = 16 PSIA (SATURATED VAPOR AT START)
AMBIENT TEMPERATURE = 500°R, COLD DUCTS



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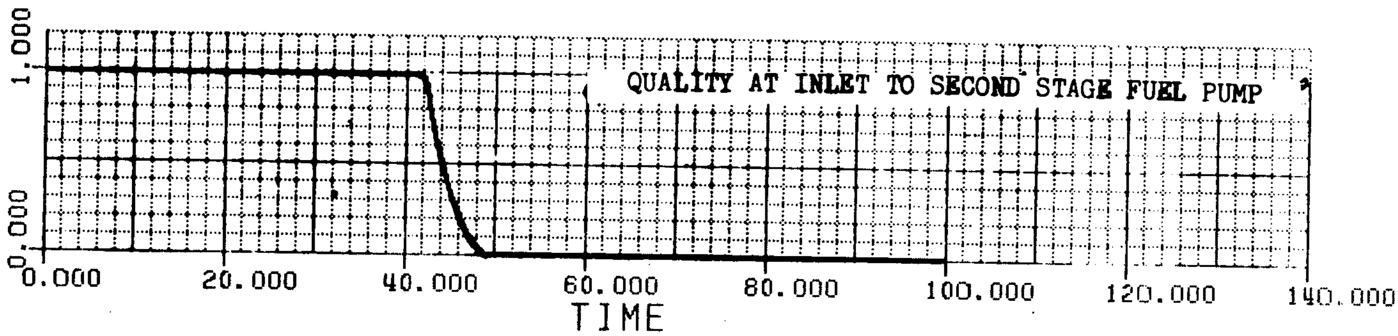
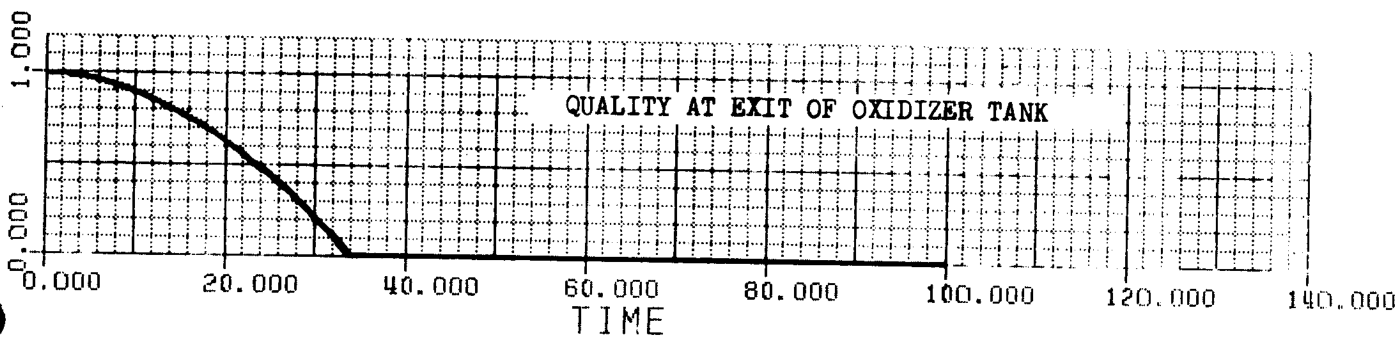
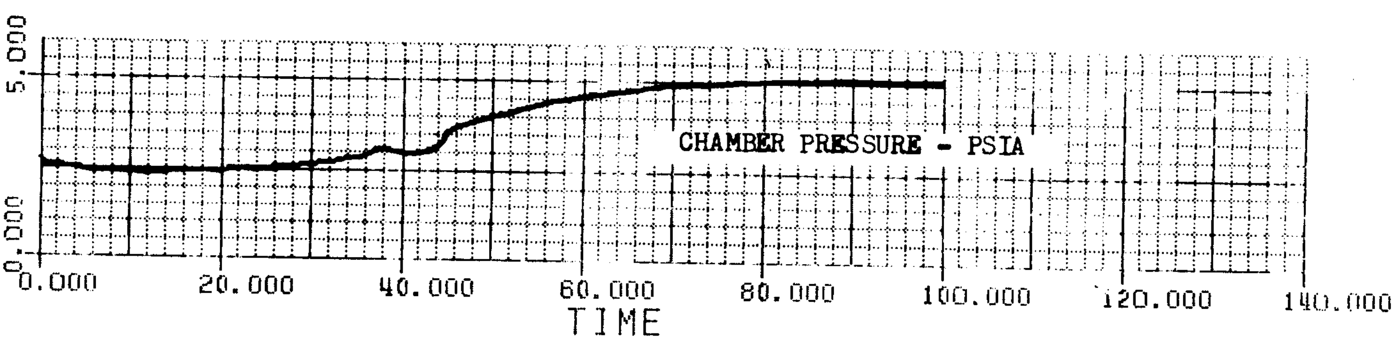
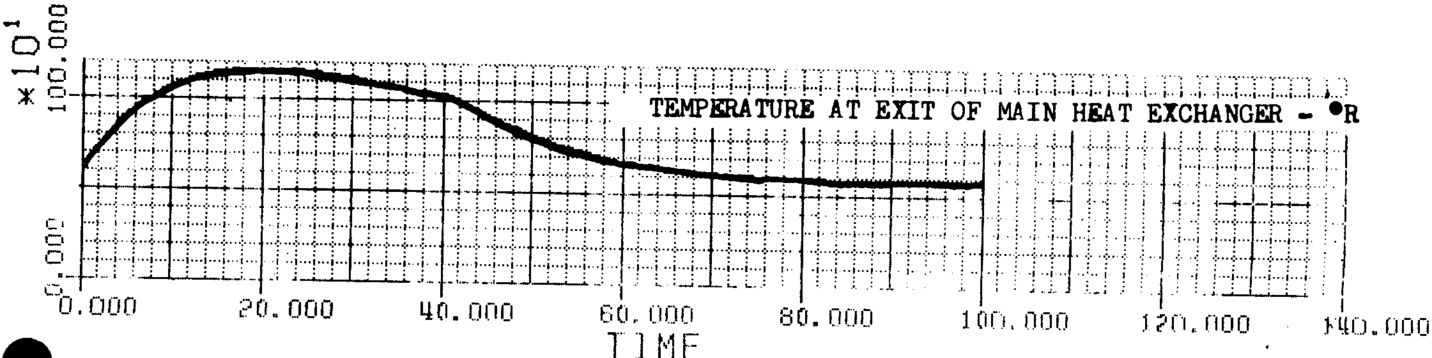
DF 97022
SHEET 1 OF 5
FIGURE III-5









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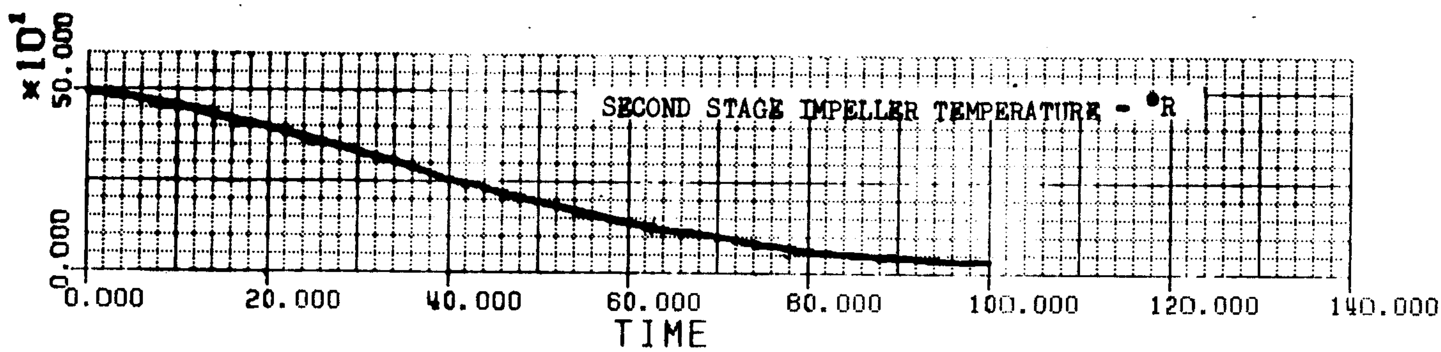
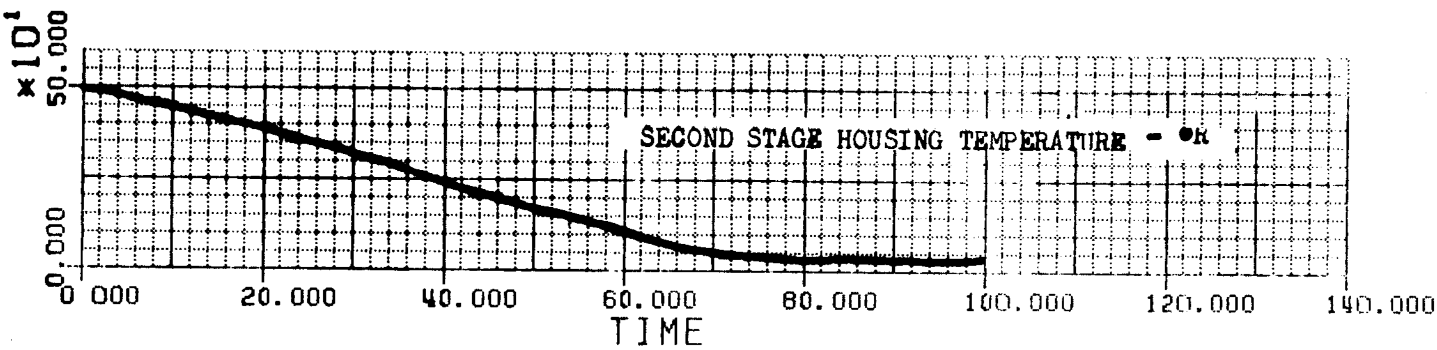
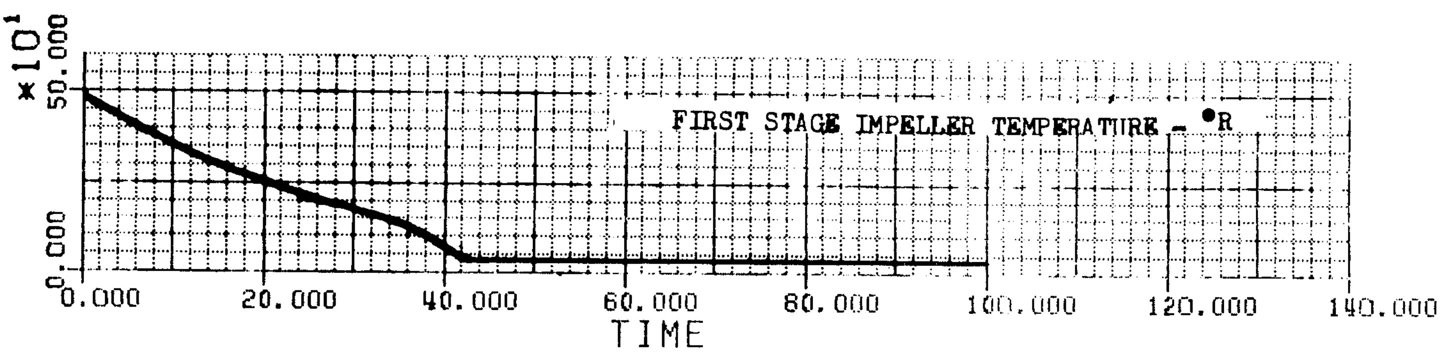
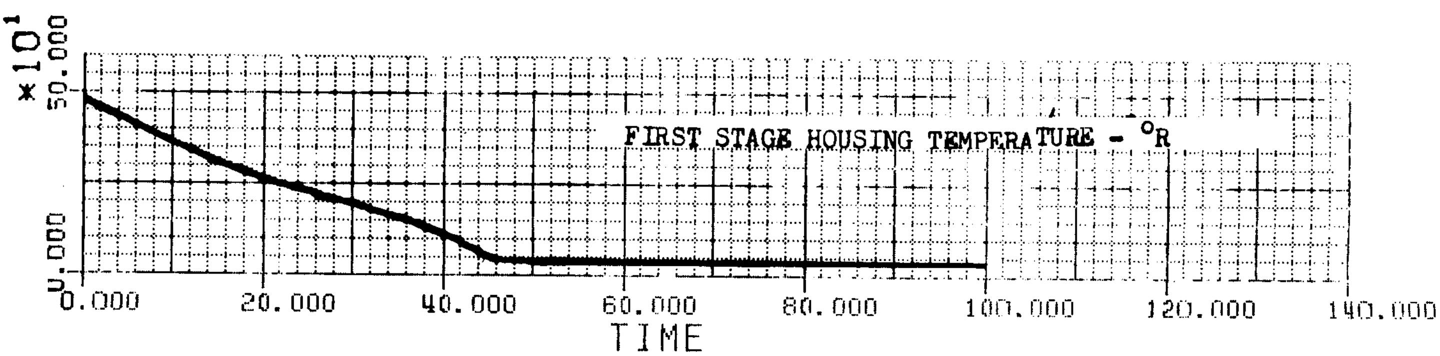
DF 97022
SHEET 2 OF 5
FIGURE III-5

FUEL PUMP









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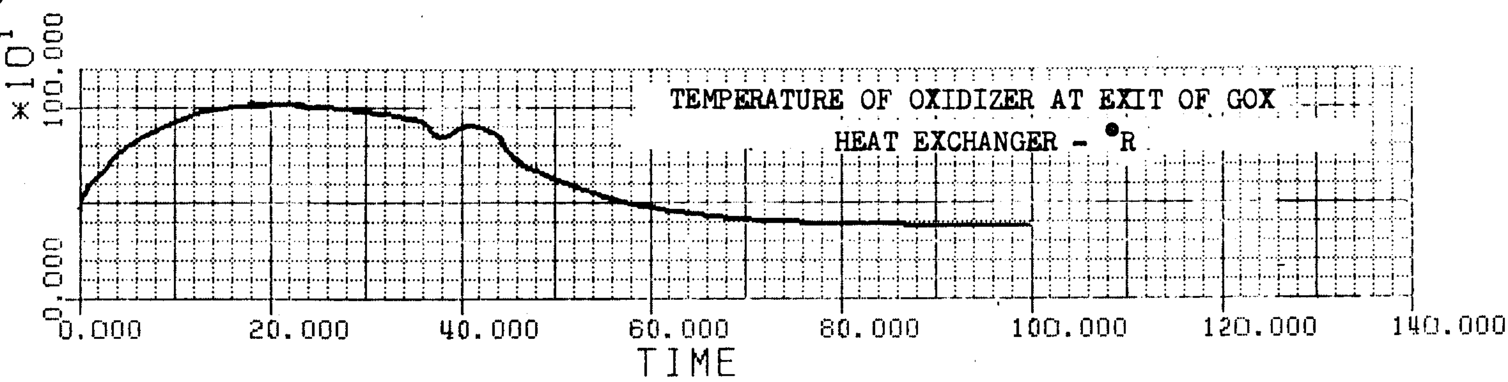
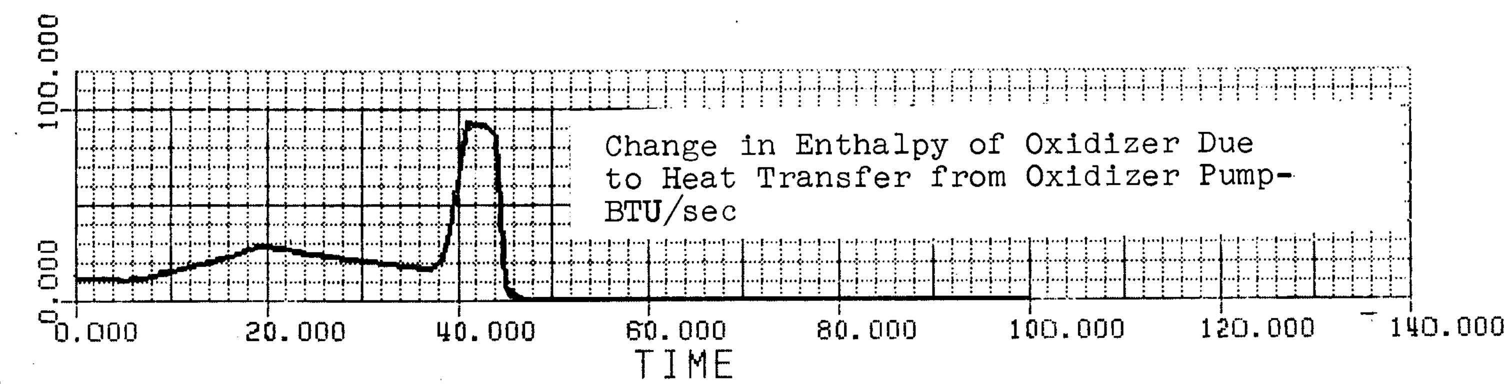
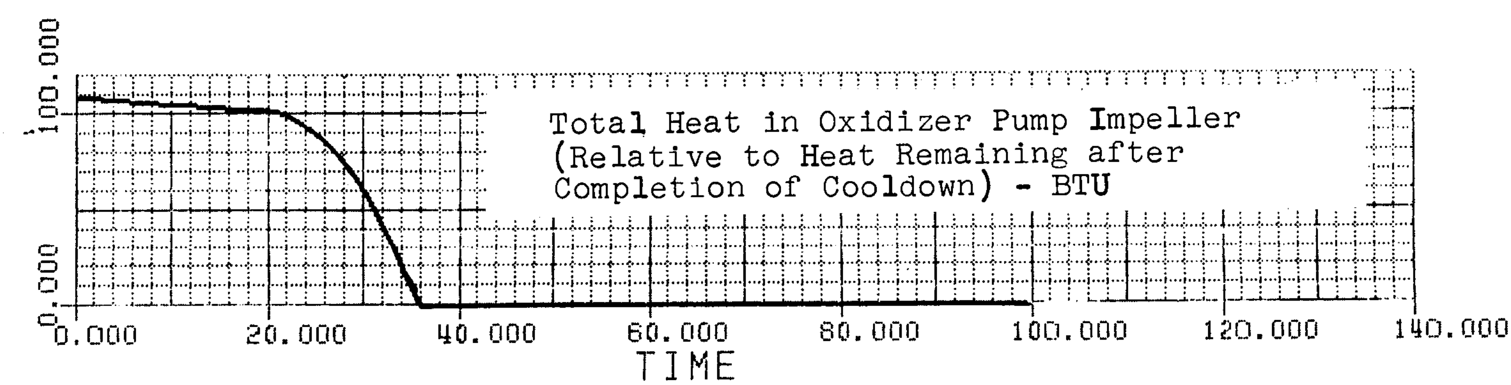
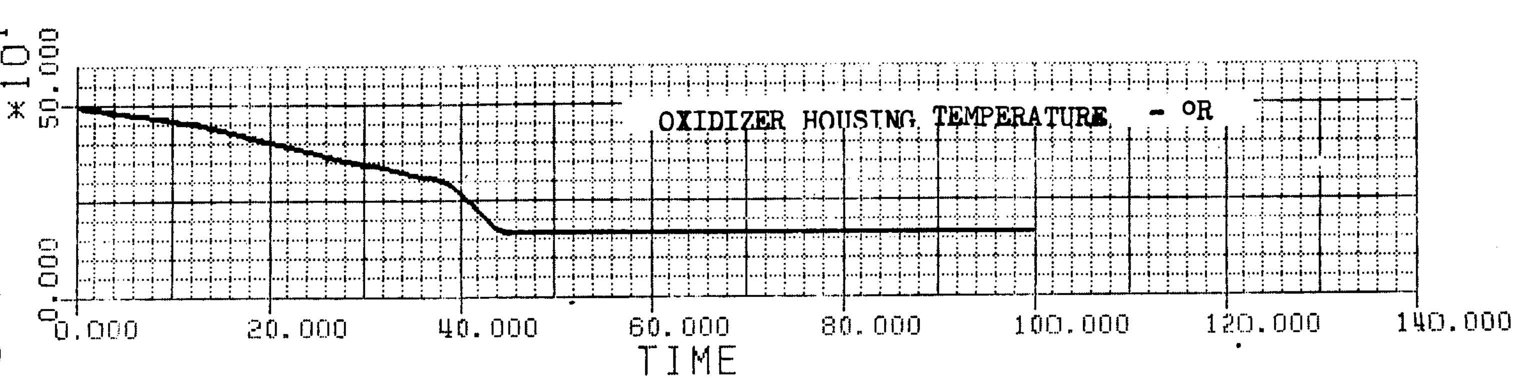
DF 97022
SHEET 3 OF 5
FIGURE III-5









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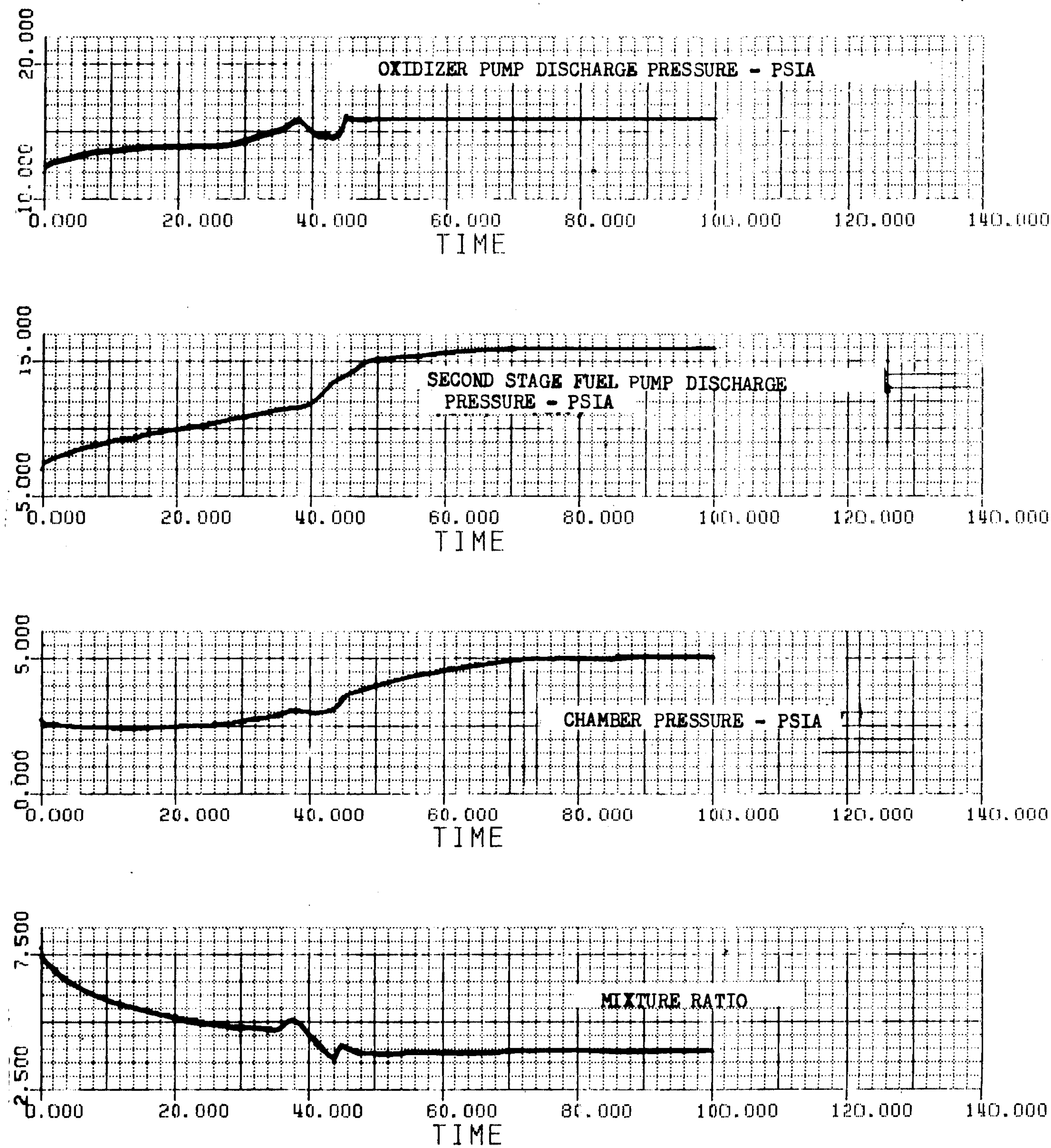
DF 97022
SHEET 4 OF 5
FIGURE III-5



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DF 97022
SHEET 5 OF 5
FIGURE III-5

PRATT & WHITNEY AIRCRAFT
SIMULATED CATEGORY IV RL10 COOLDOWN TRANSIENT

INLET CONDITIONS: P = 16 PSIA SATURATED VAPOR AT START
AMBIENT TEMPERATURE = 500°R, COLD DUCTS

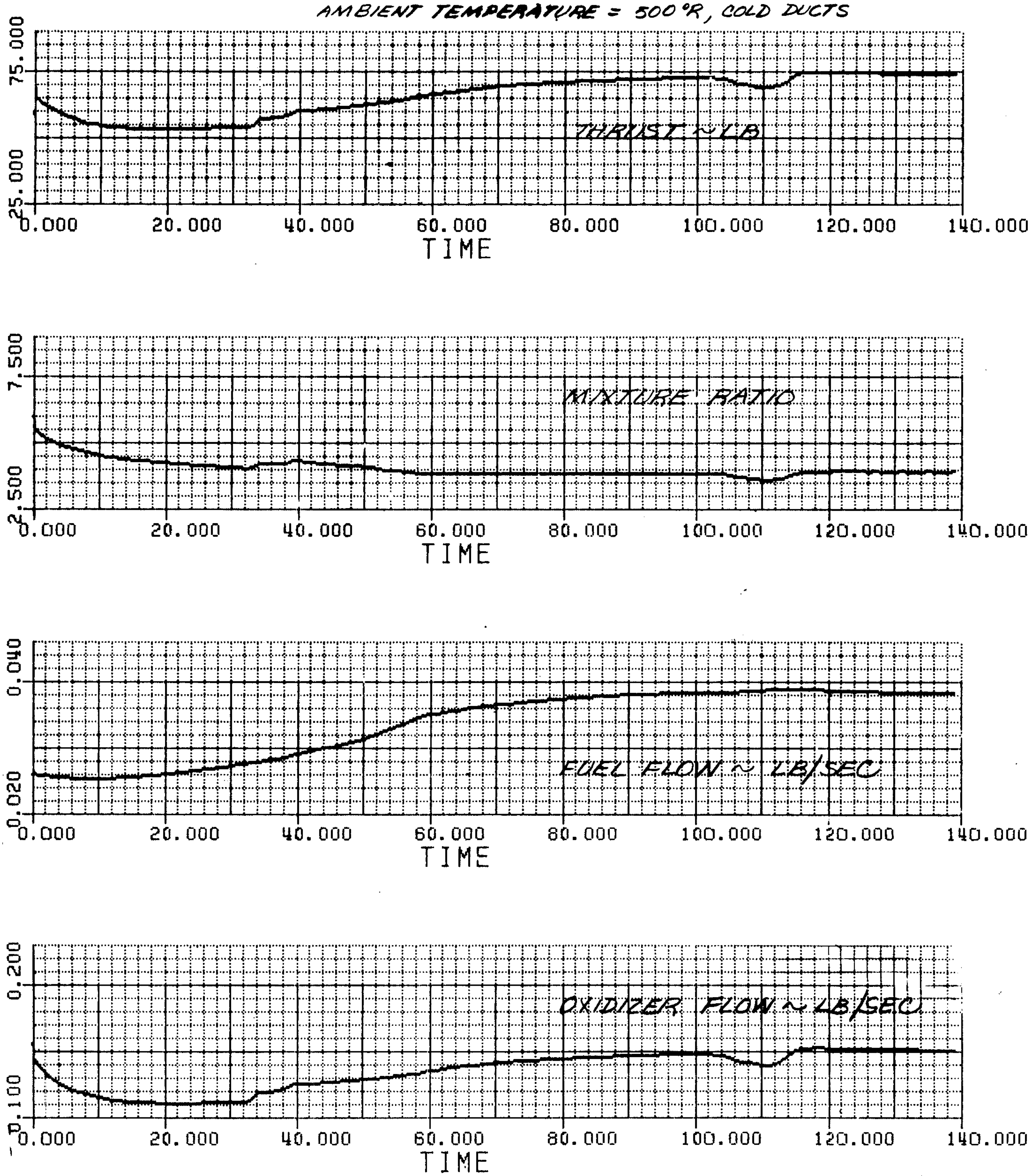

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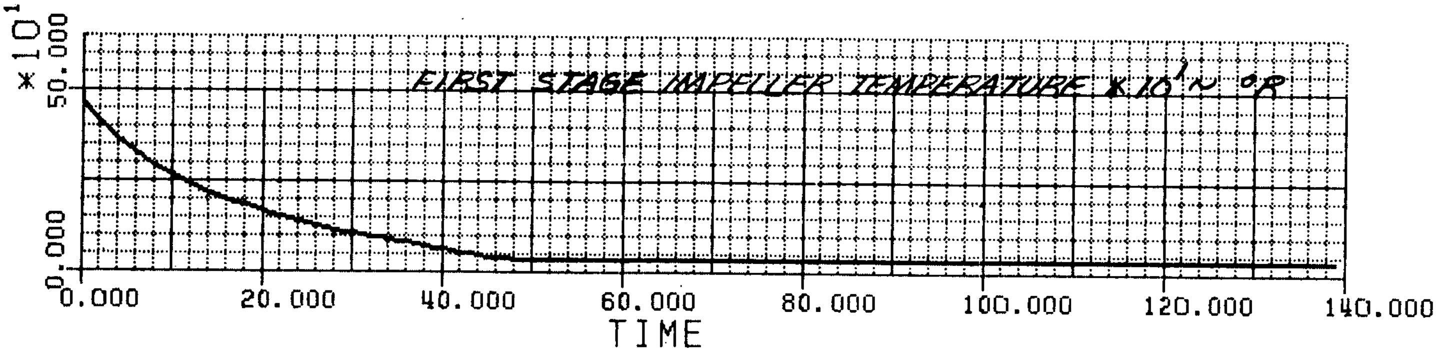
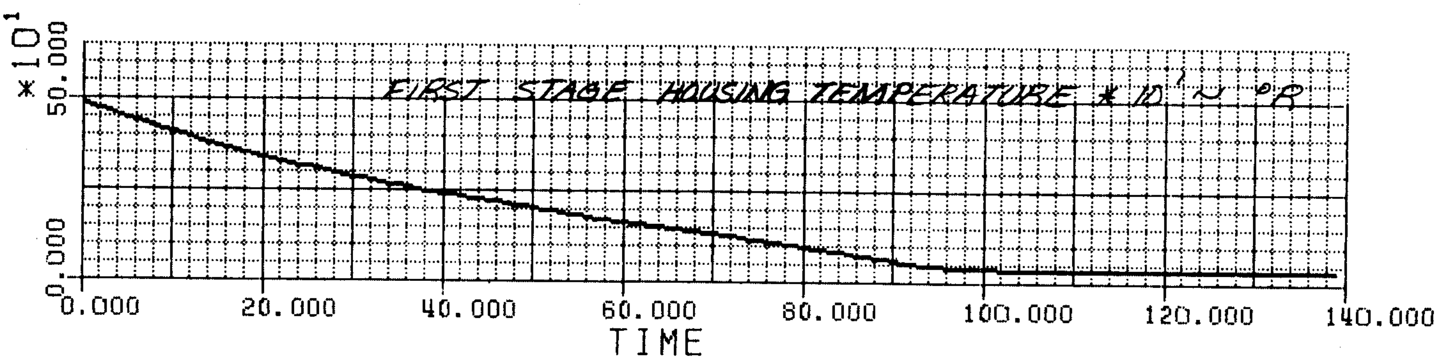
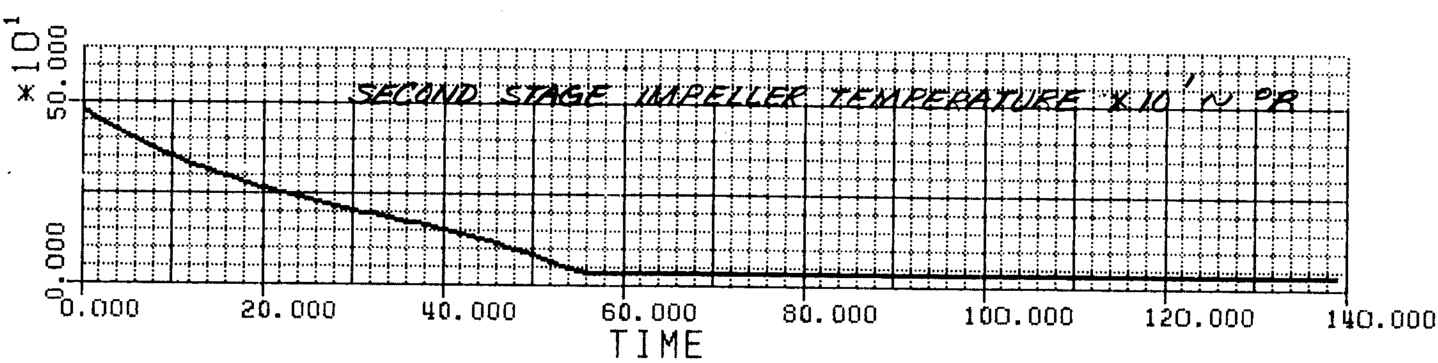
FIGURE III-6

FUEL PUMP







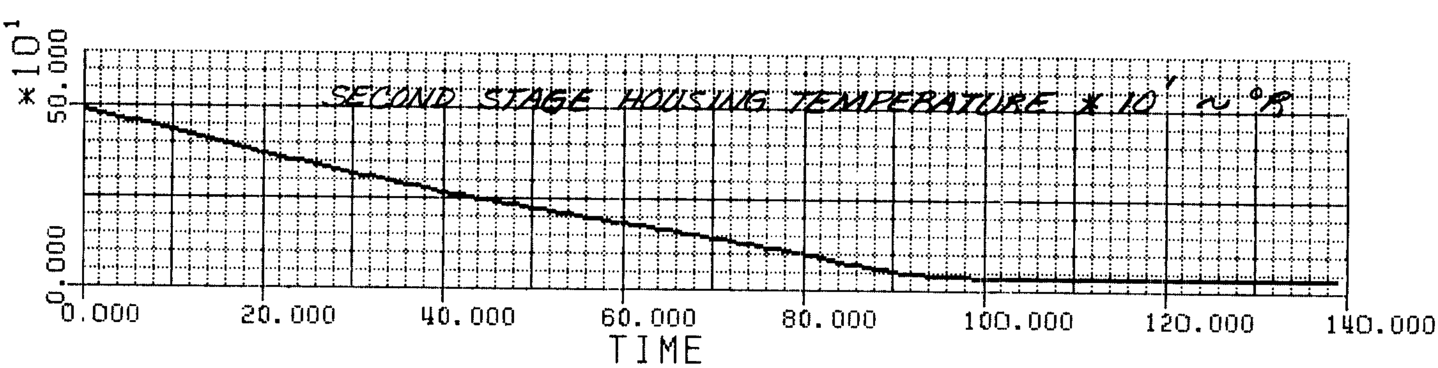


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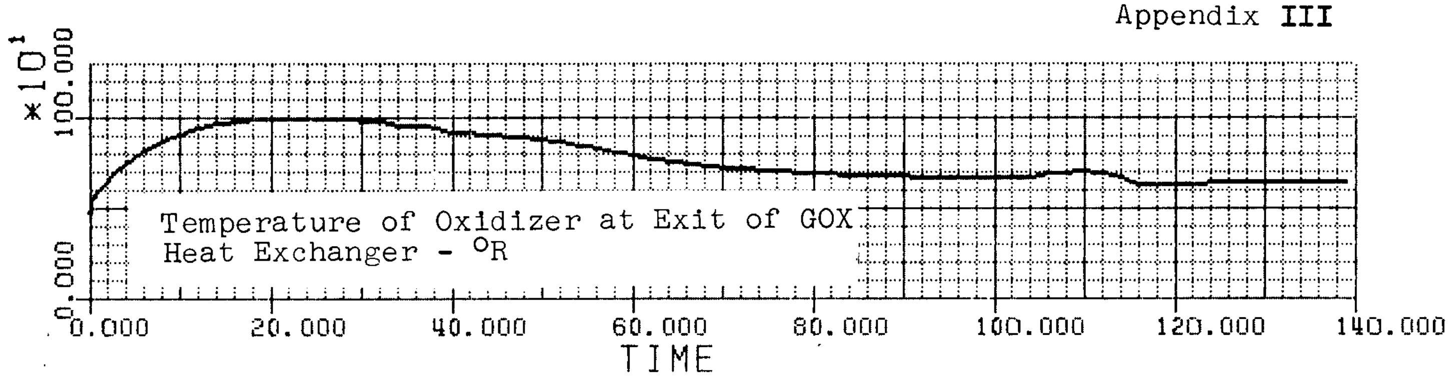
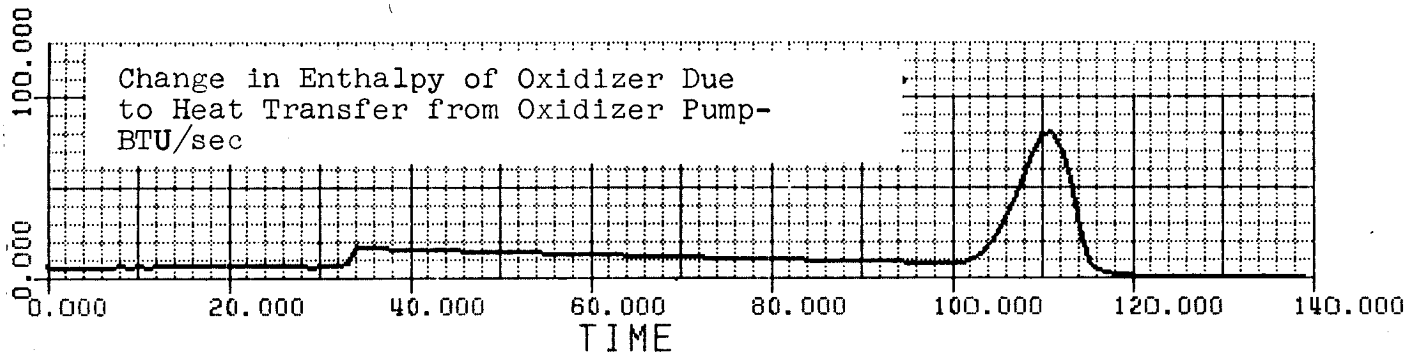
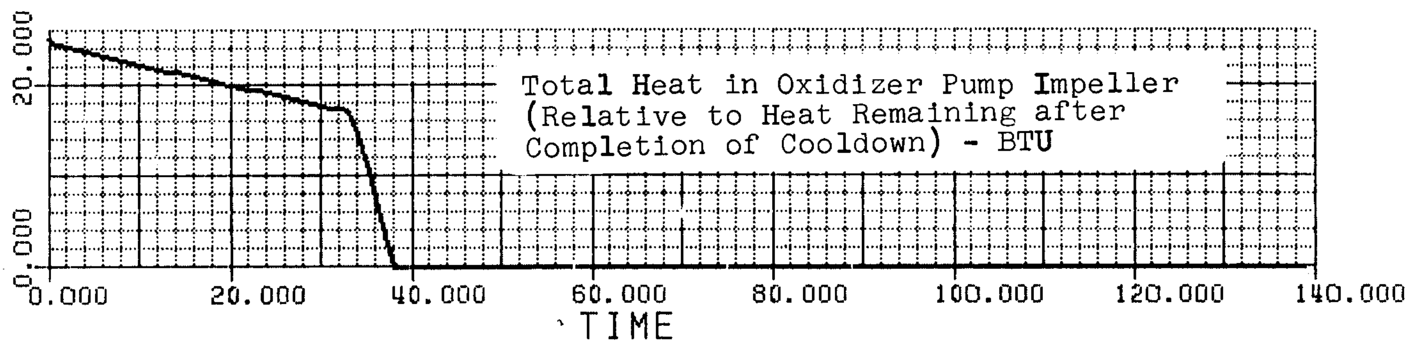
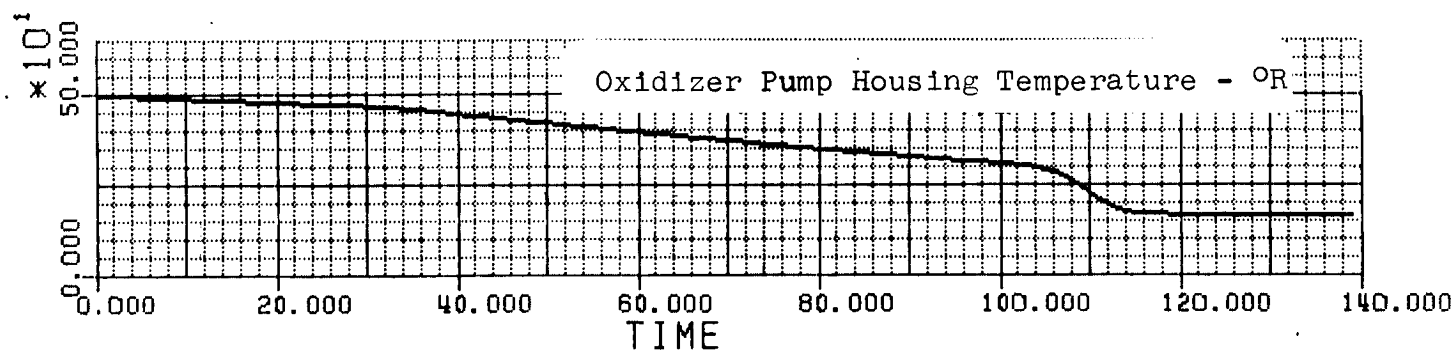
FIGURE III-6









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REVISION A
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FIGURE III-6

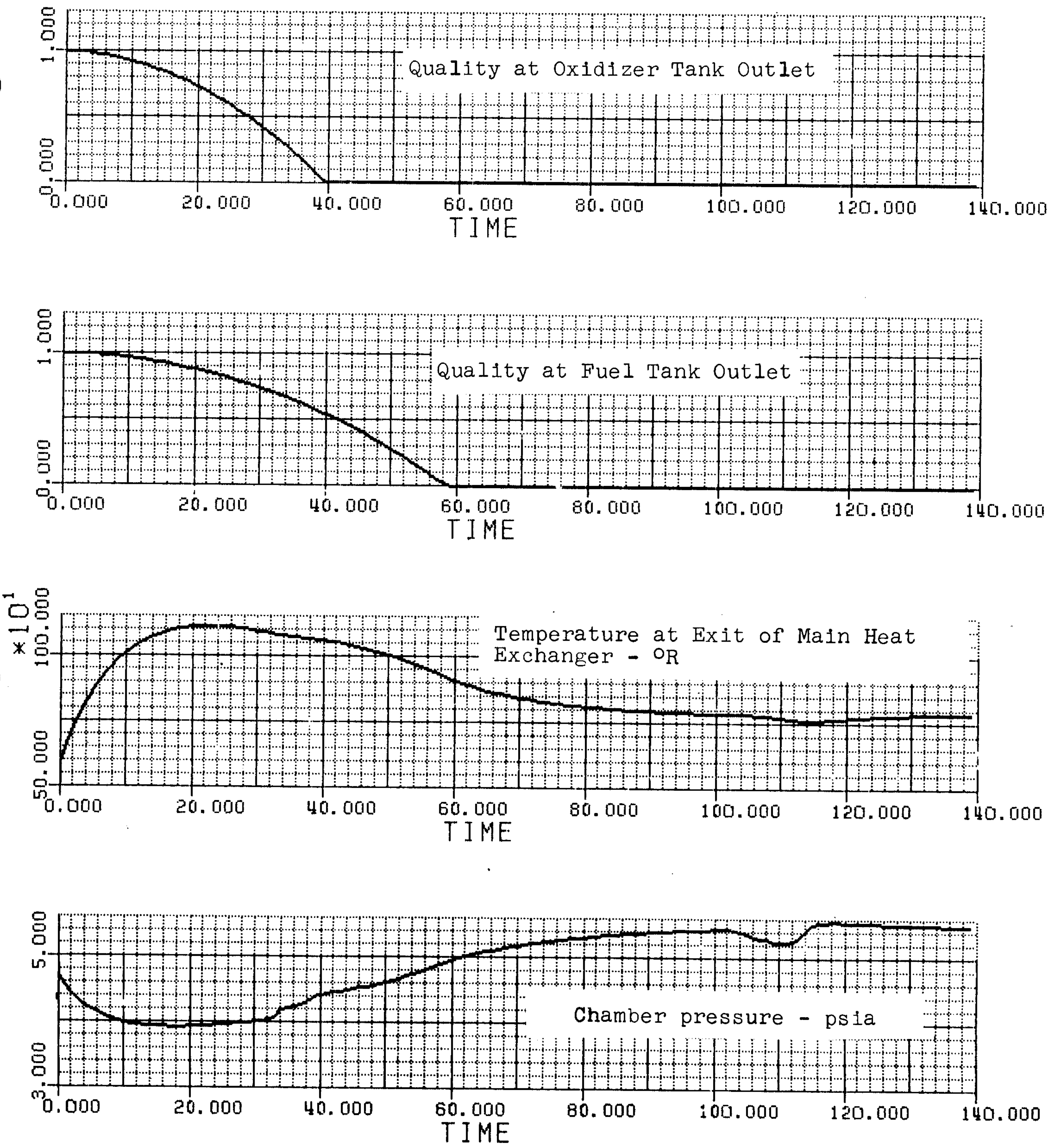

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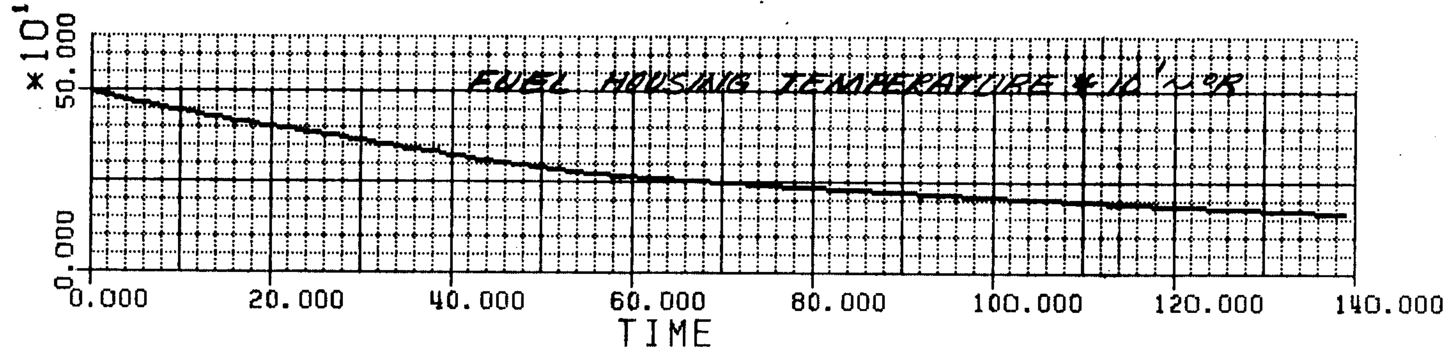
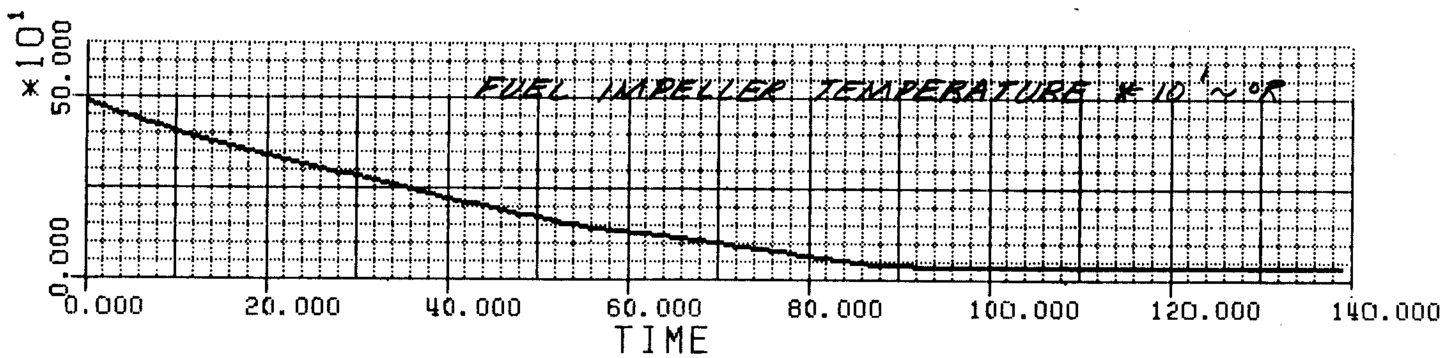
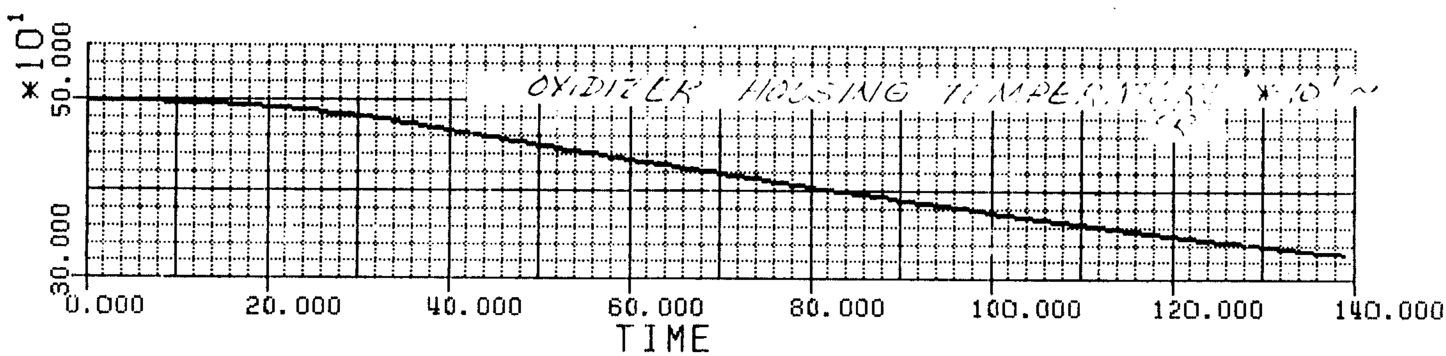
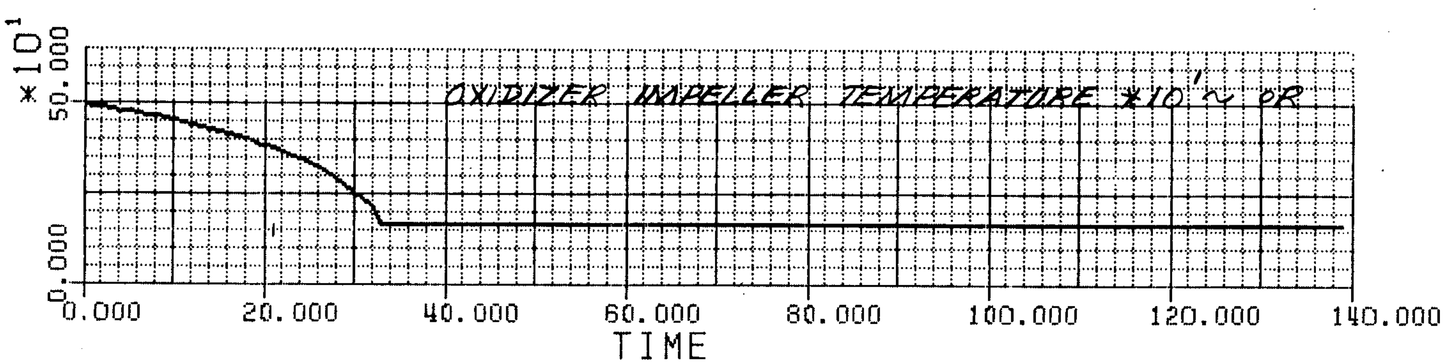
FIGURE III-6

BOOST PUMPS









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DF 97024
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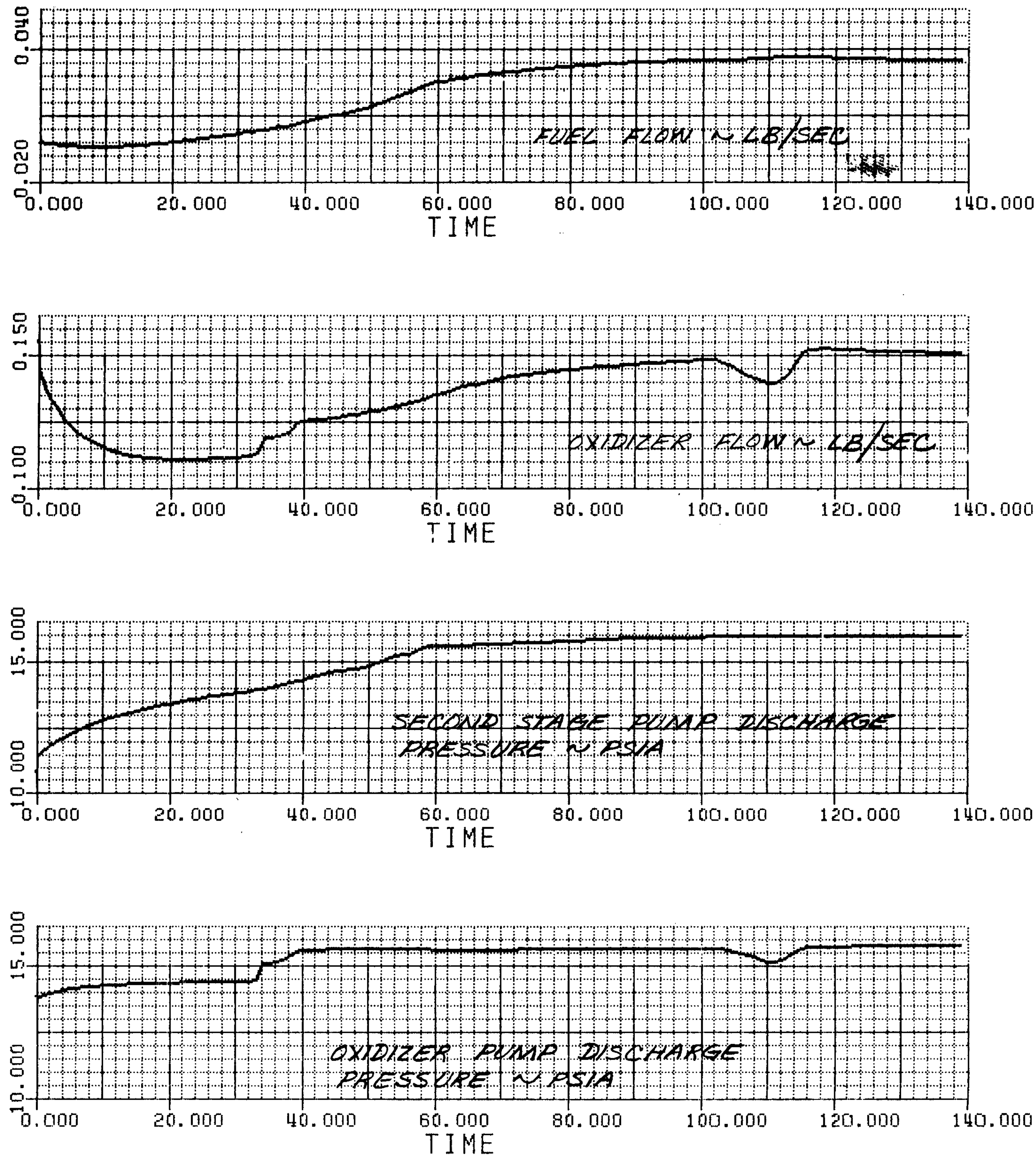
FIGURE III-6



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DF 97024
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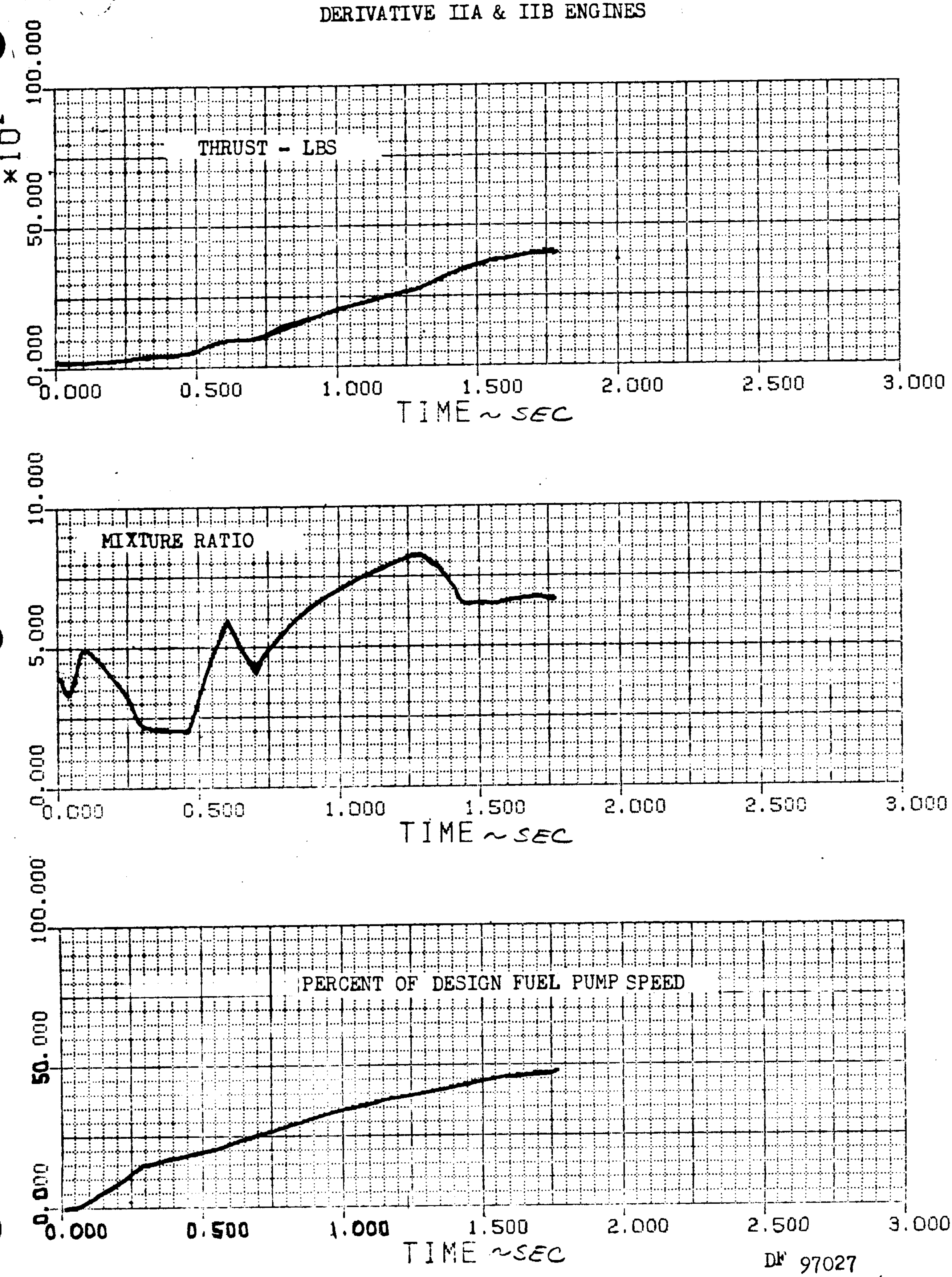
FIGURE III-6

PRATT & WHITNEY AIRCRAFT
SIMULATED START TRANSIENT FROM TANK HEAD IDLE TO MANEUVERING THRUST (PUMPED IDLE)
DERIVATIVE IIA & IIB ENGINES



DF 97027
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FIGURE III-7

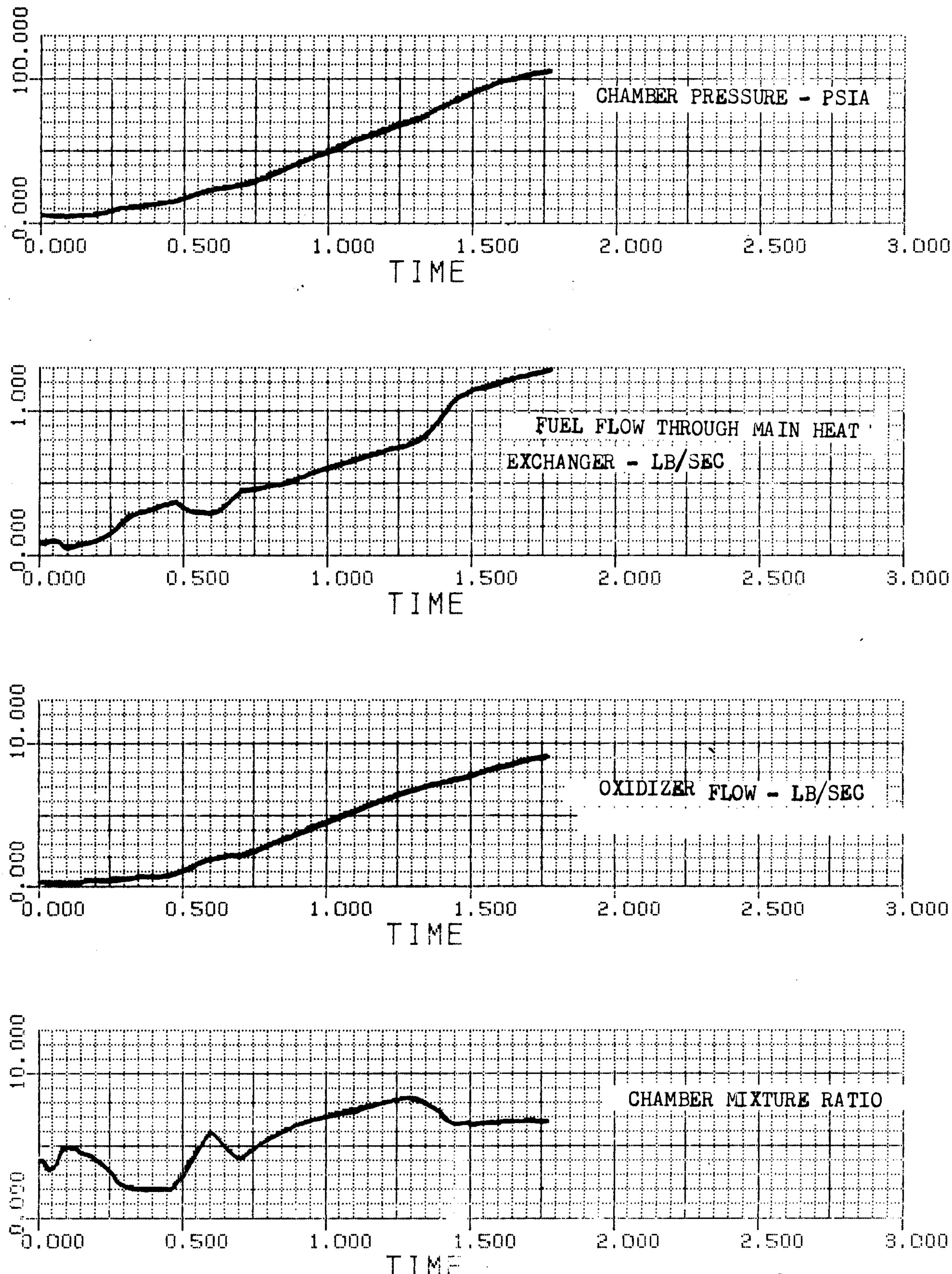

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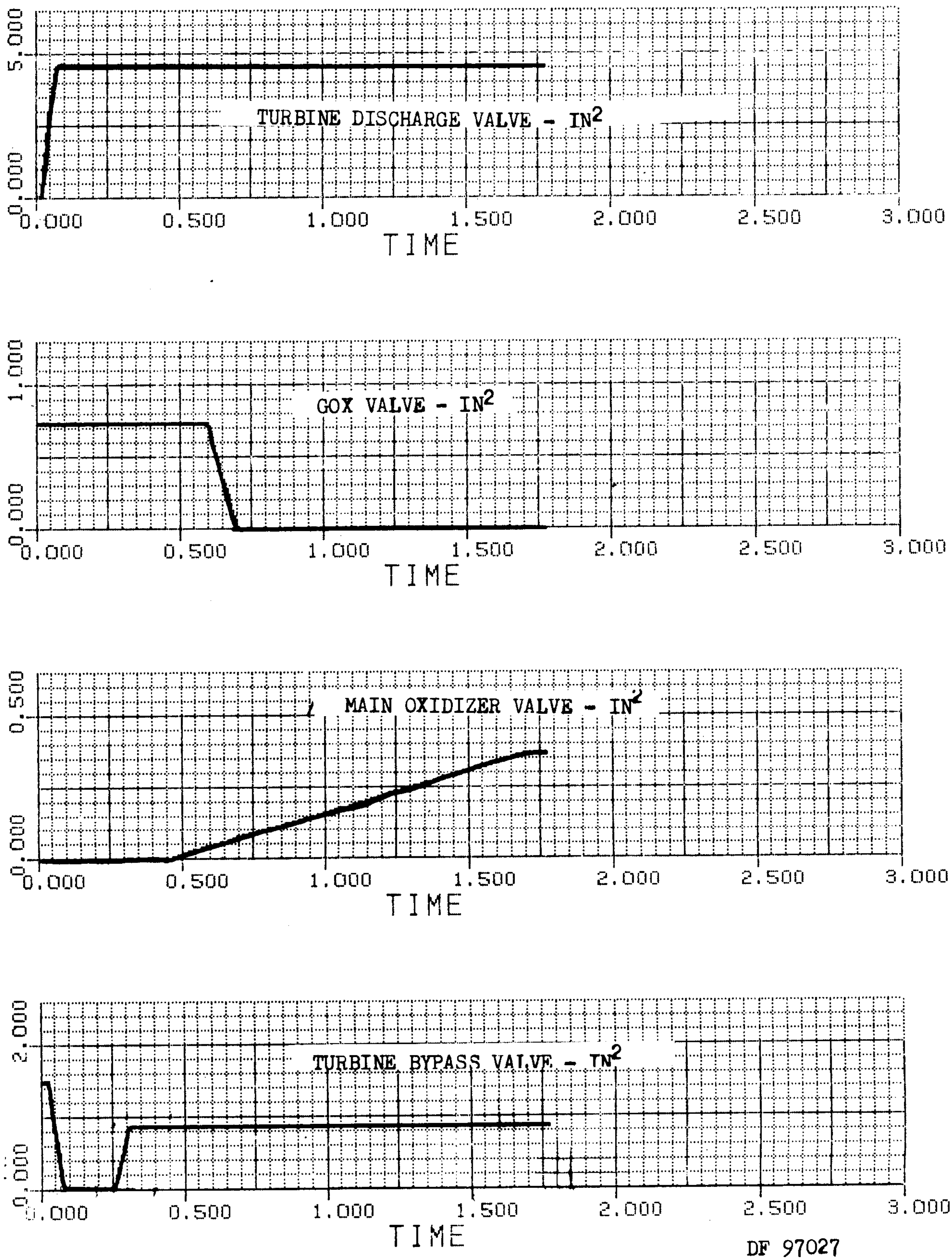
FIGURE III-7

VALVE AREAS



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SHEET 3 OF 5

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FIGURE III-7

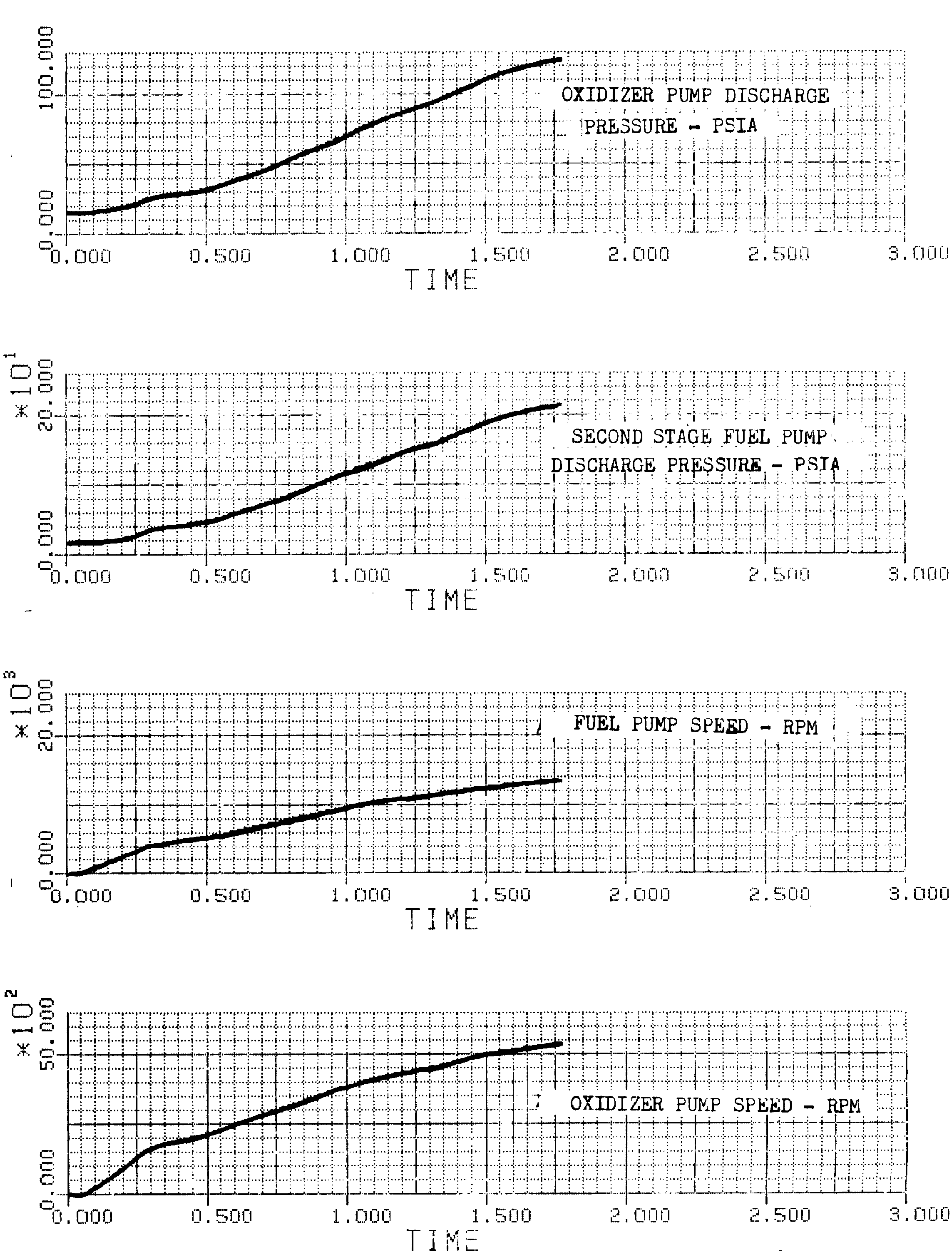

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FIGURE III-7

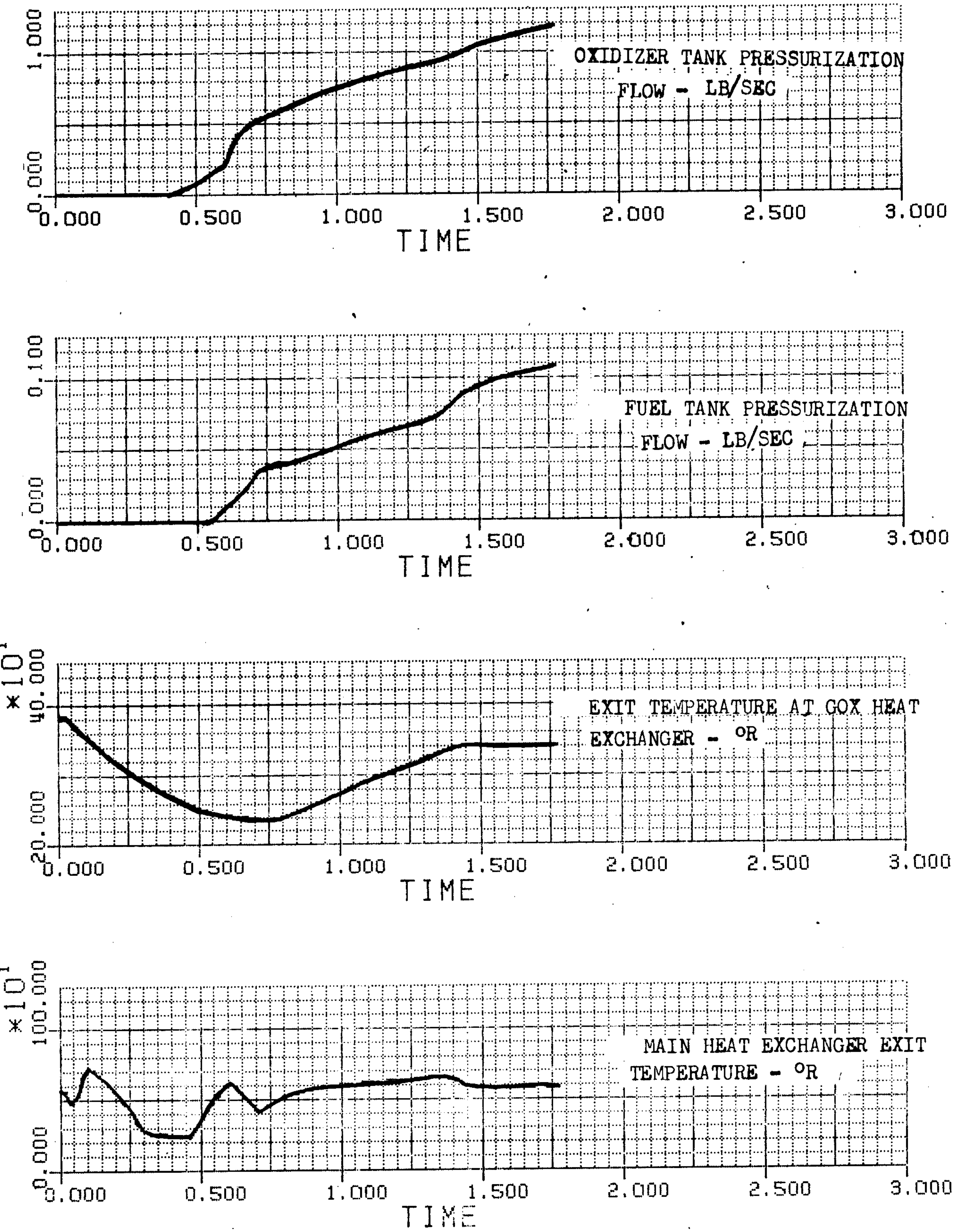

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FIGURE III-7

PRATT & WHITNEY AIRCRAFT
SIMULATED START TRANSIENT FROM MANEUVERING THRUST TO FULL THRUST
DERIVATIVE IIA & IIB ENGINES

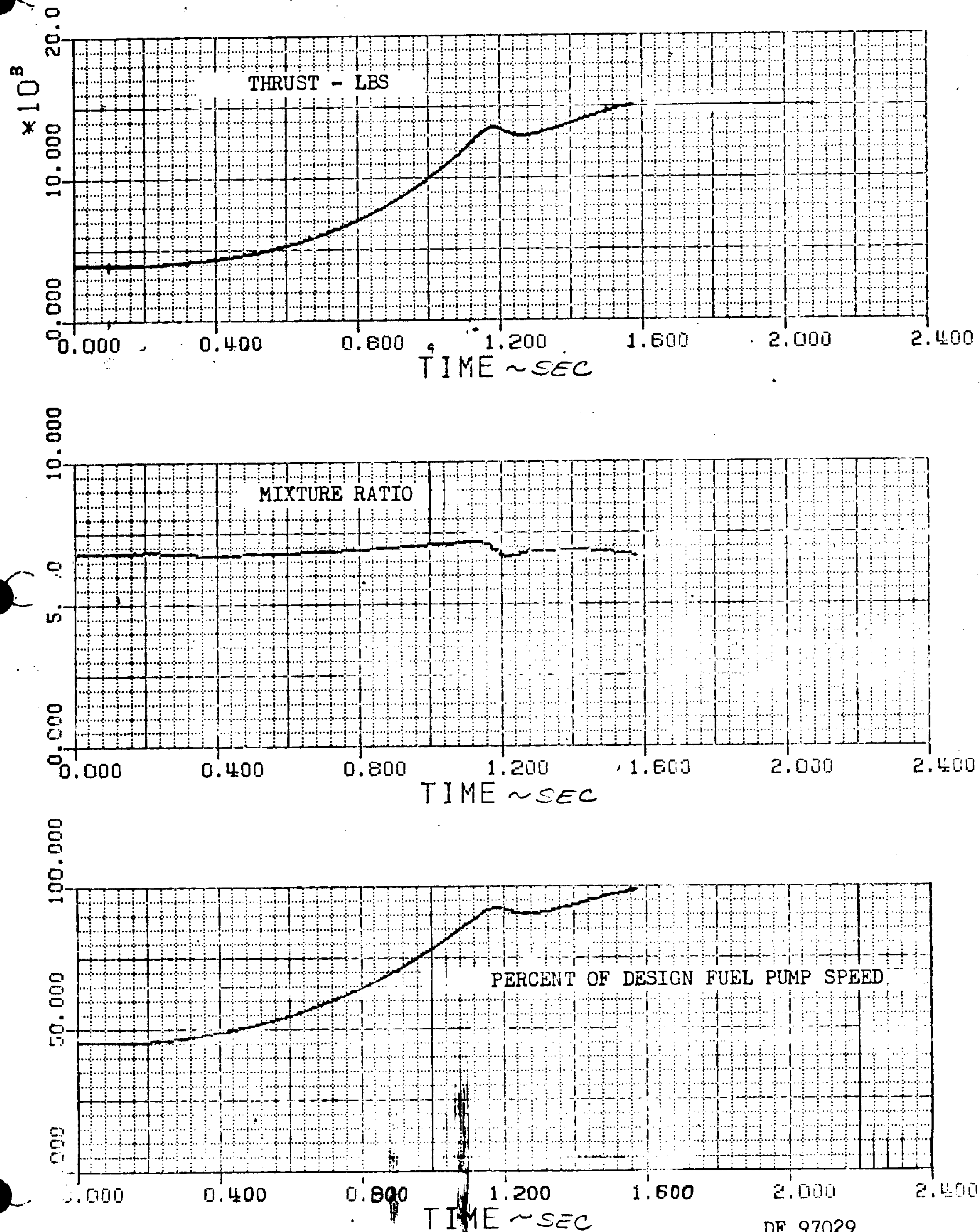

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FIGURE III-8

VALVE AREAS

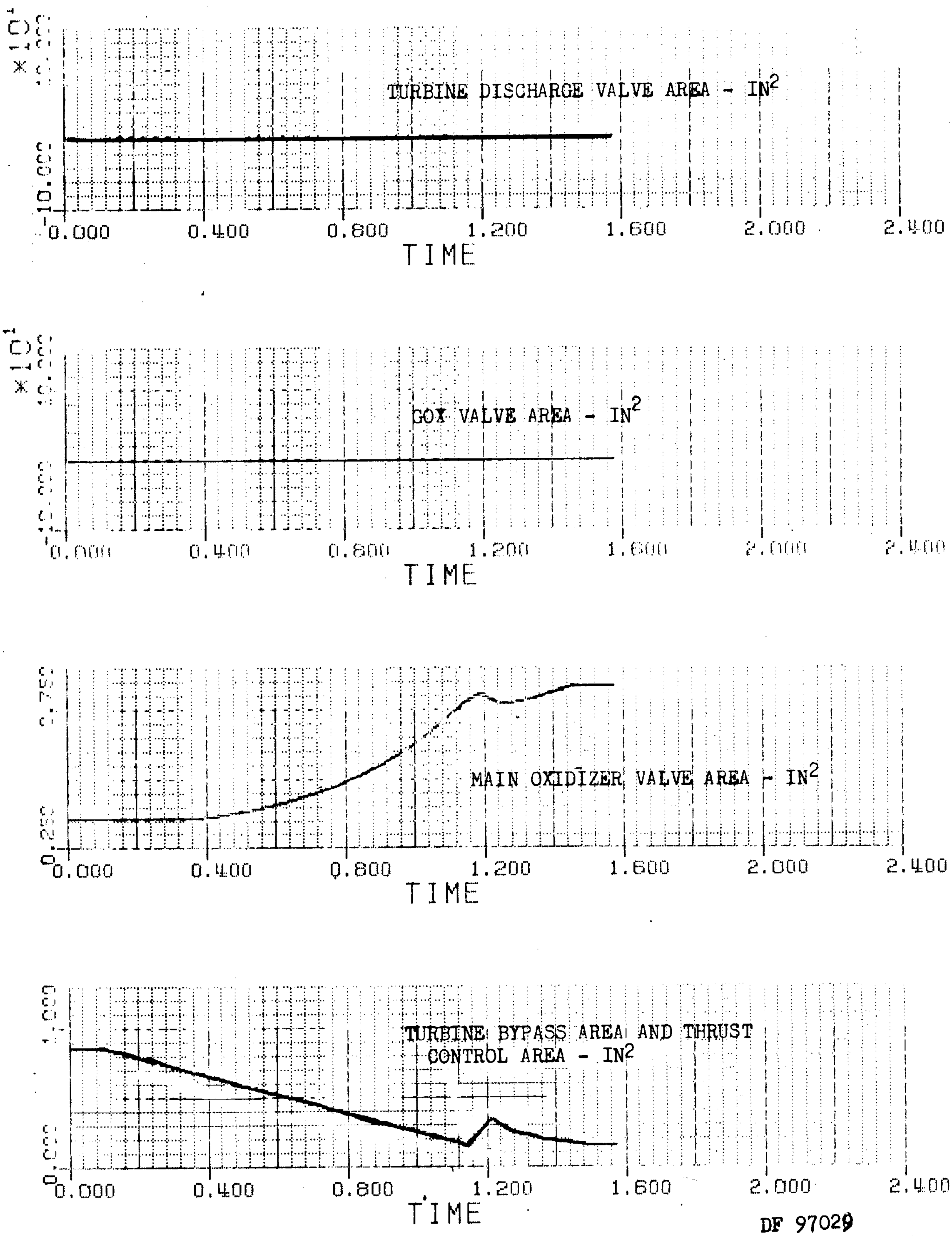

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FIGURE III-8

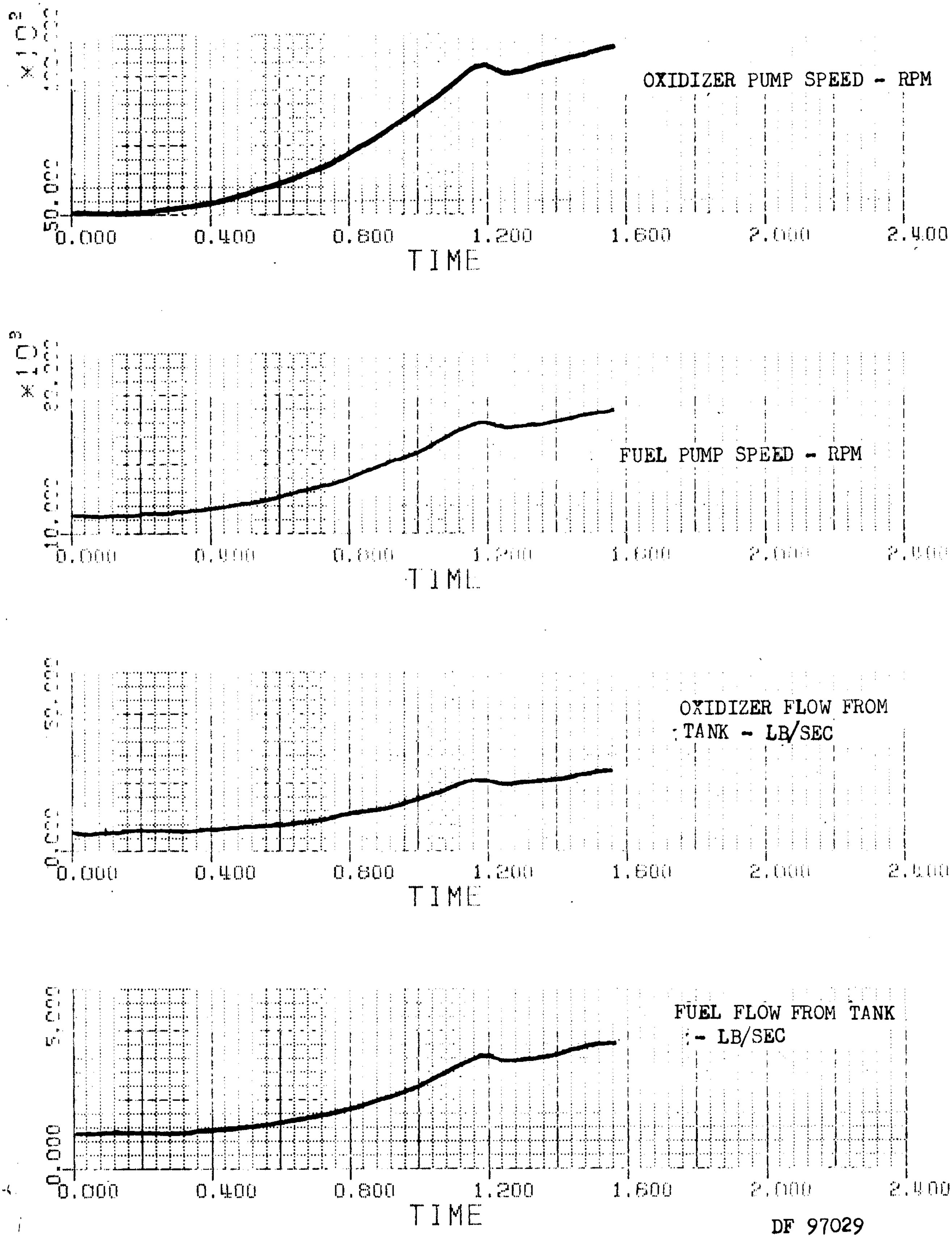

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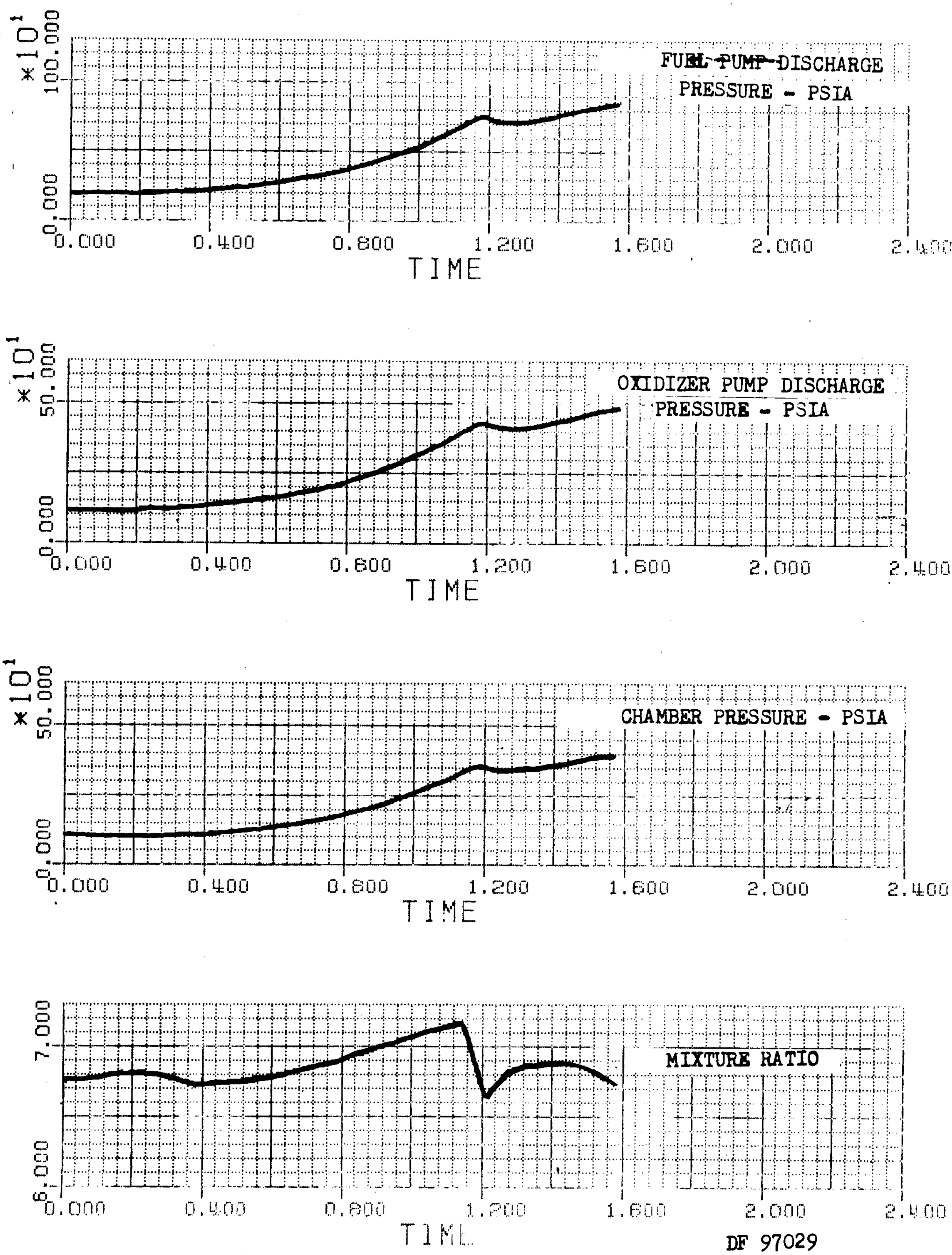
FIGURE III-8



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SHEET 4 OF 5

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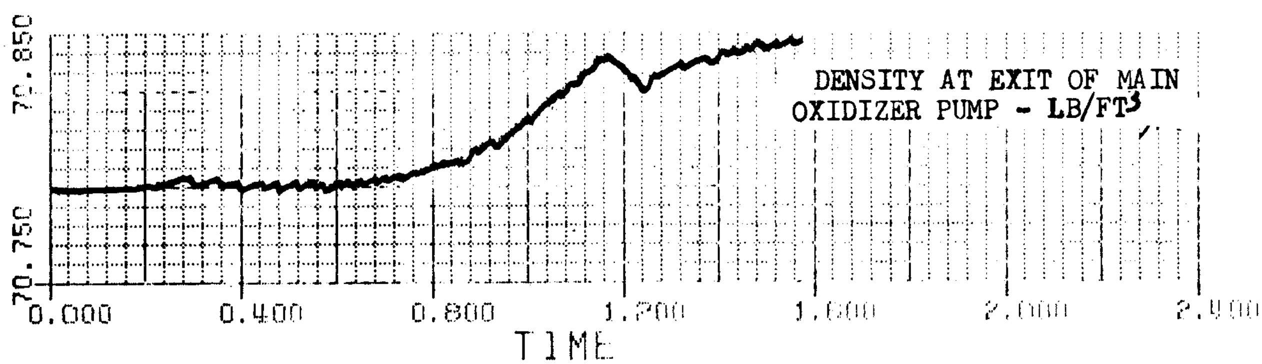
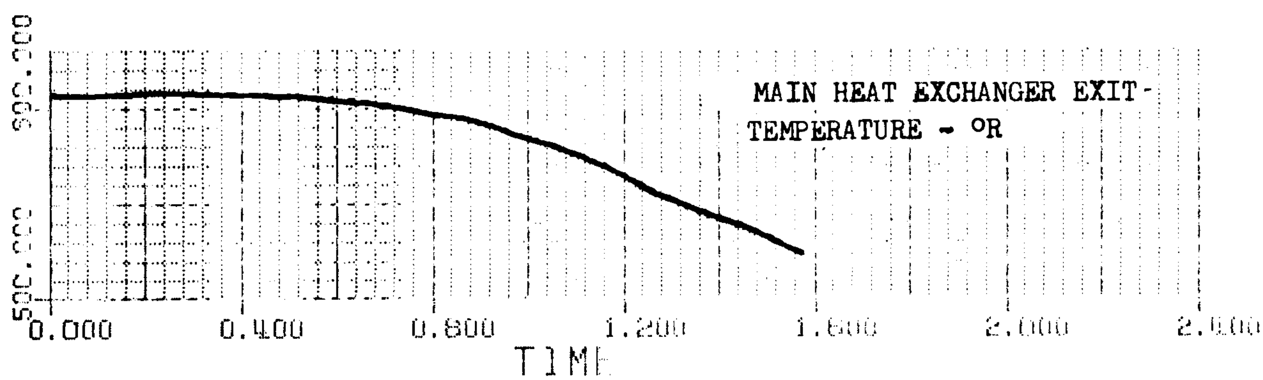
FIGURE III-8





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DF 97029
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FIGURE III-8

PRATT & WHITNEY AIRCRAFT
SIMULATED TRANSIENT FROM FULL THRUST TO MANEUVERING THRUST (PUMPED IDLE)
DERIVATIVE IIA & IIB ENGINES

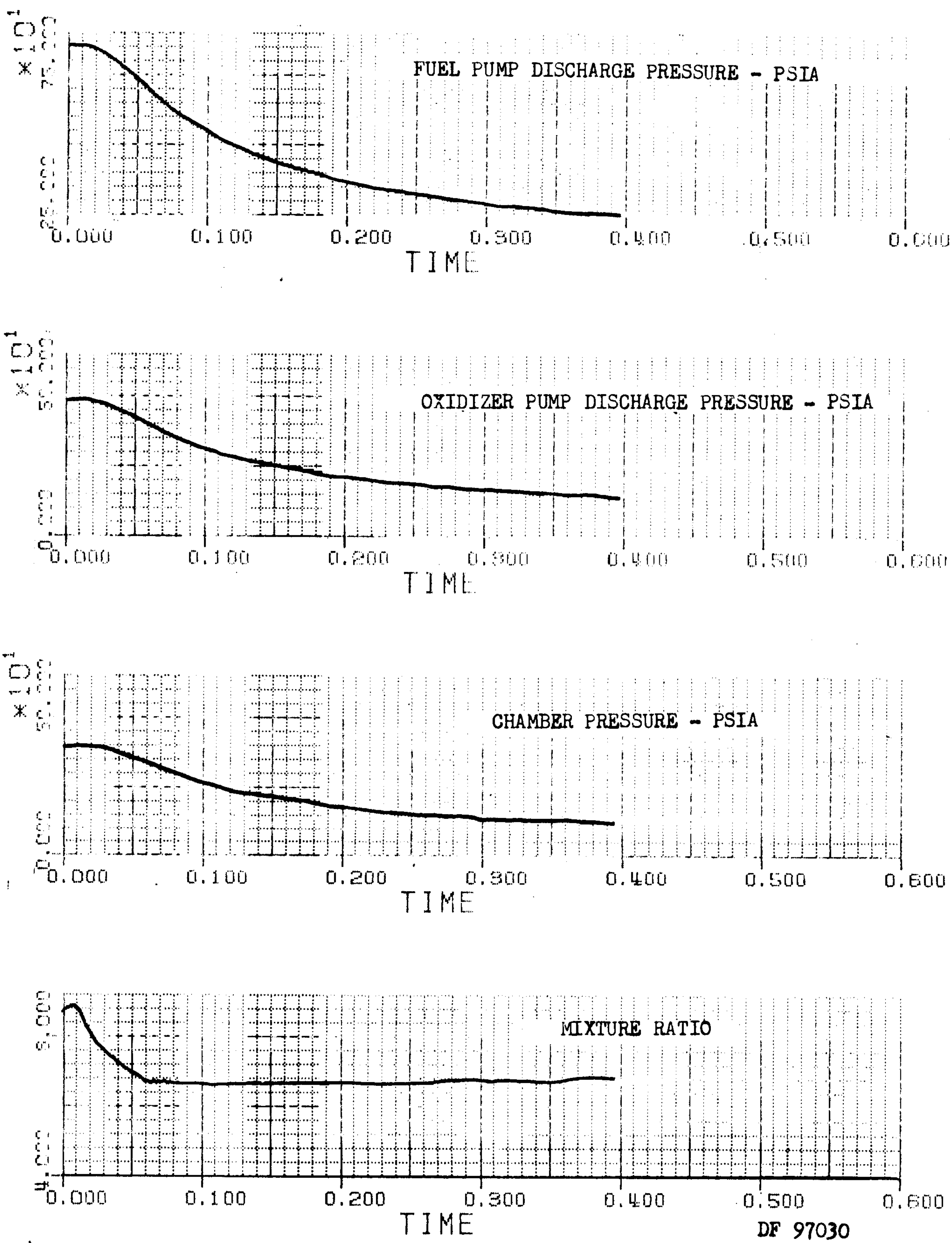

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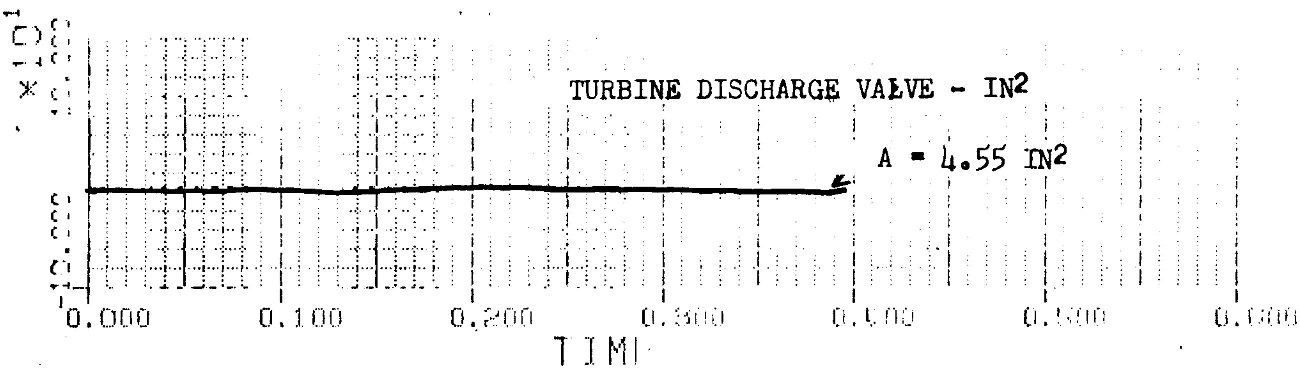
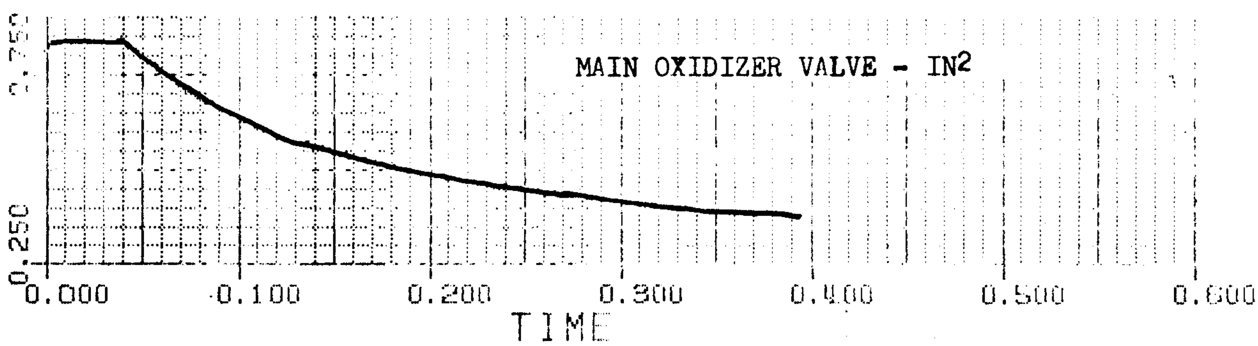
FIGURE III-9

VALVE AREAS





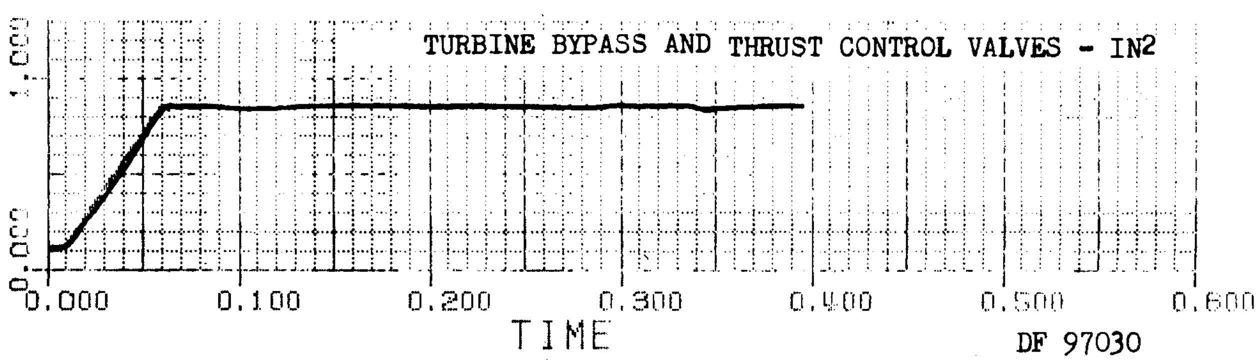


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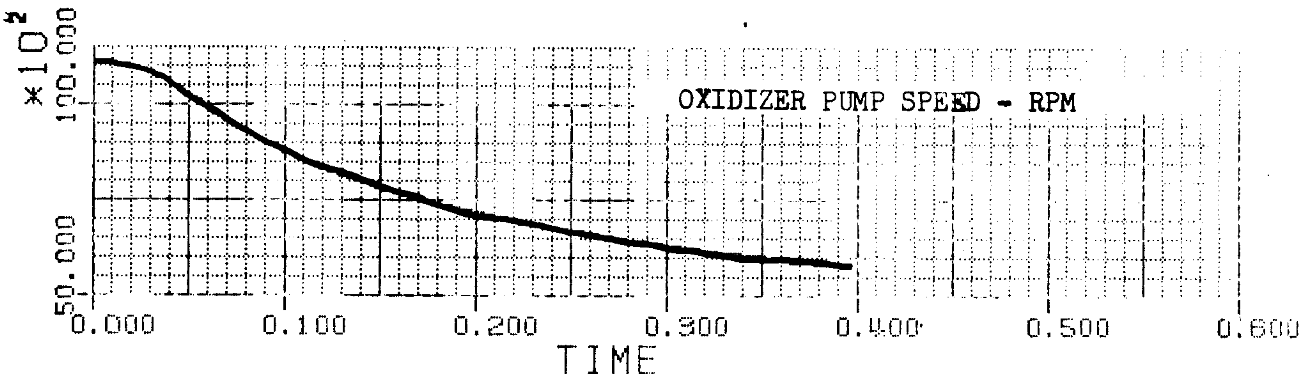
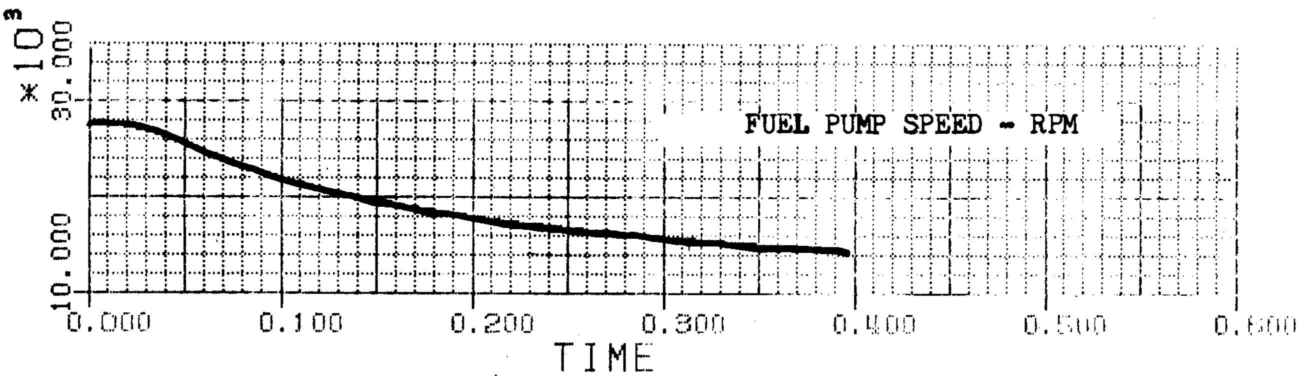
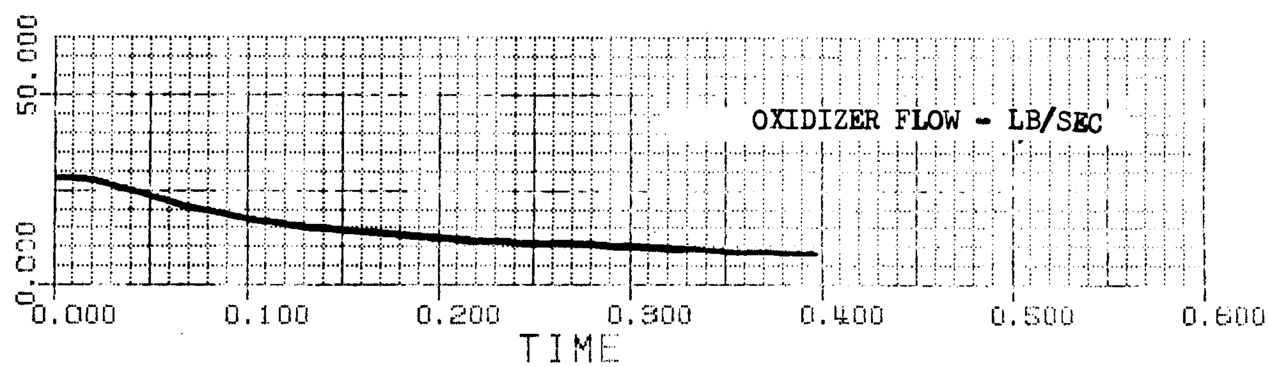
FIGURE III-9







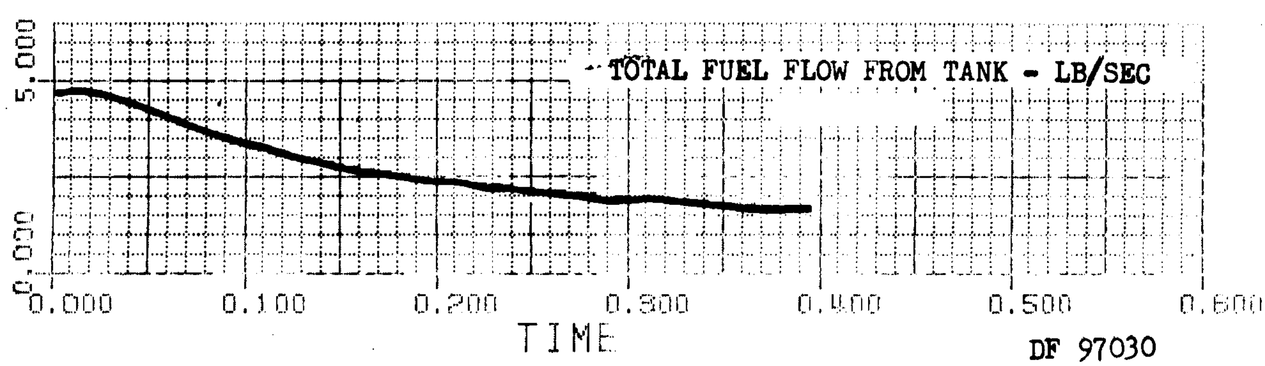


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FIGURE III-9

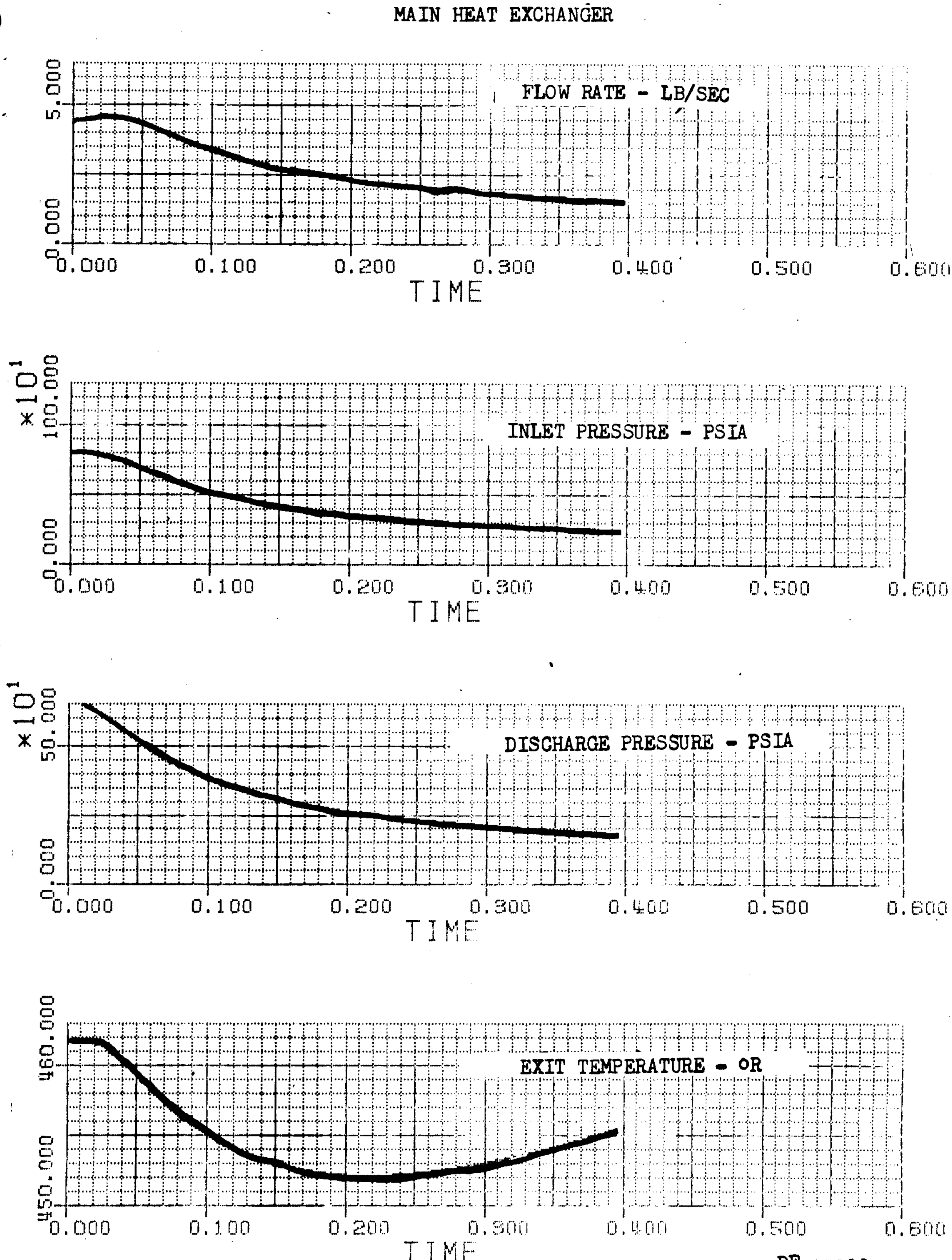

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FIGURE III-9

PRATT & WHITNEY AIRCRAFT
SIMULATED TRANSIENT FROM MANEUVERING THRUST TO TANK HEAD IDLE
DERIVATIVE IIA & IIB ENGINES

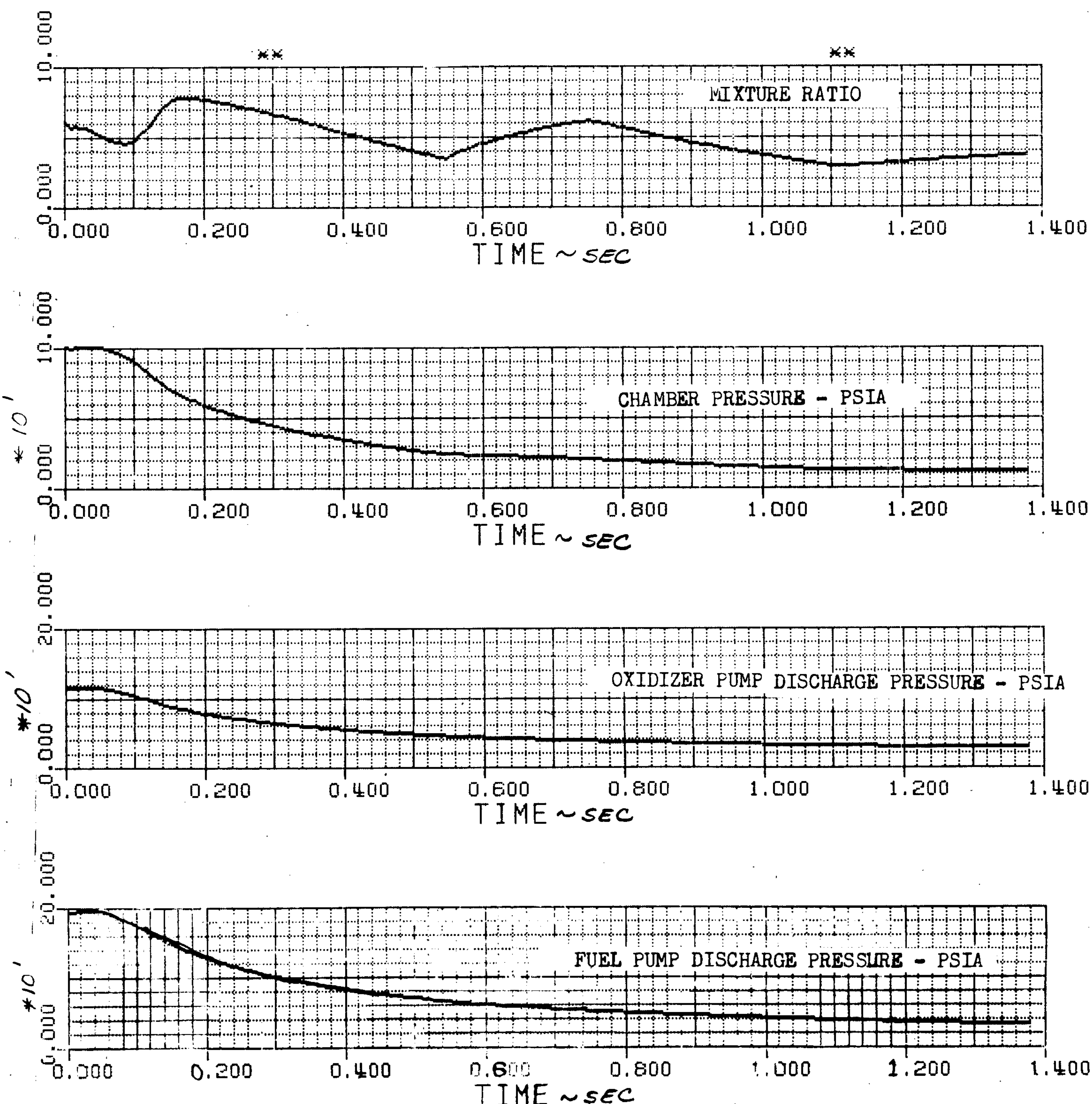

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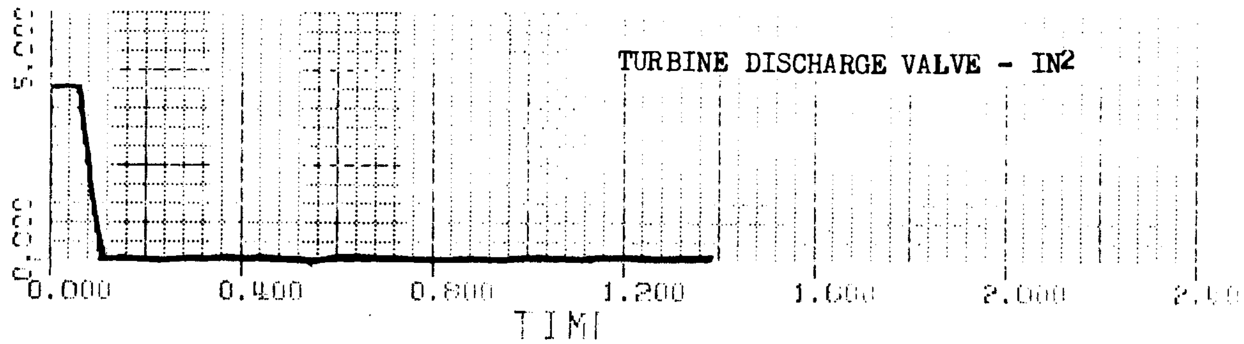
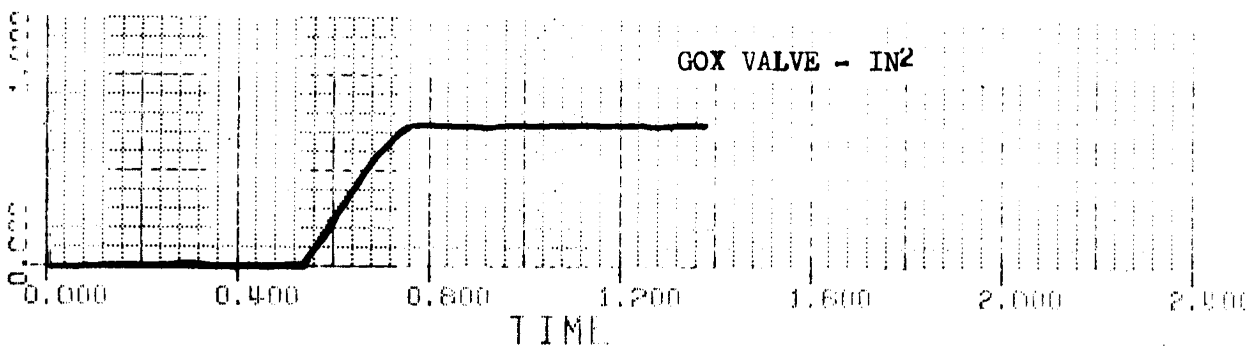
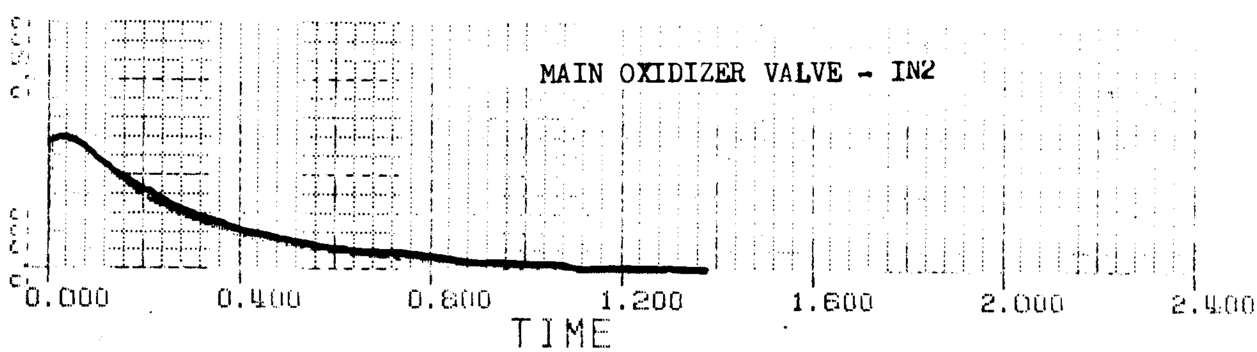
FIGURE III-10

VALVE AREAS







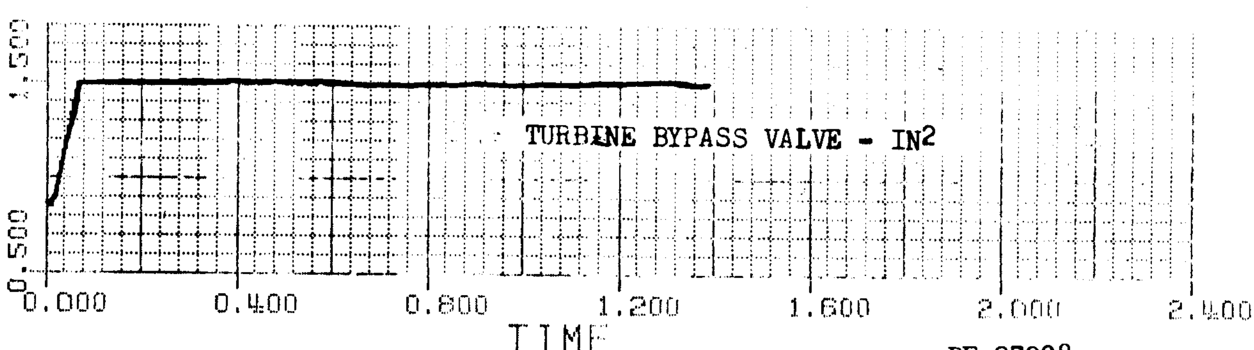


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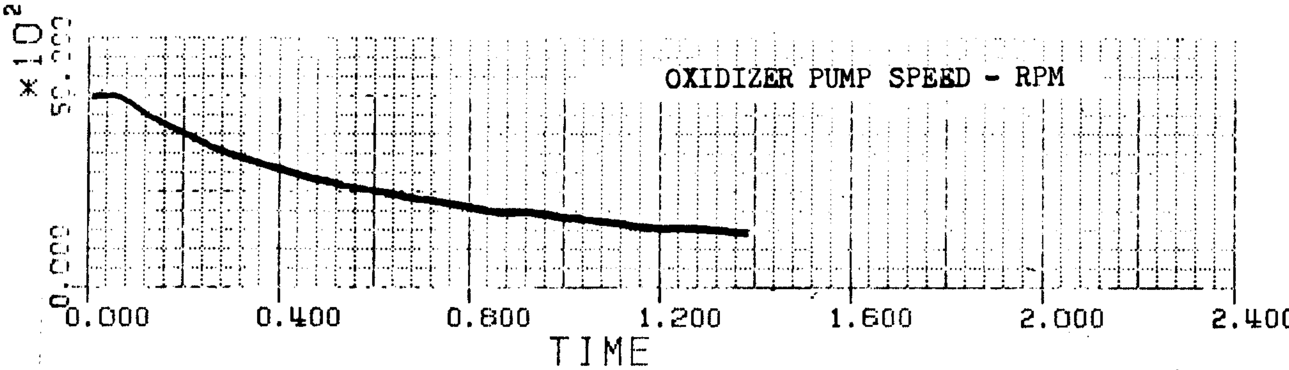
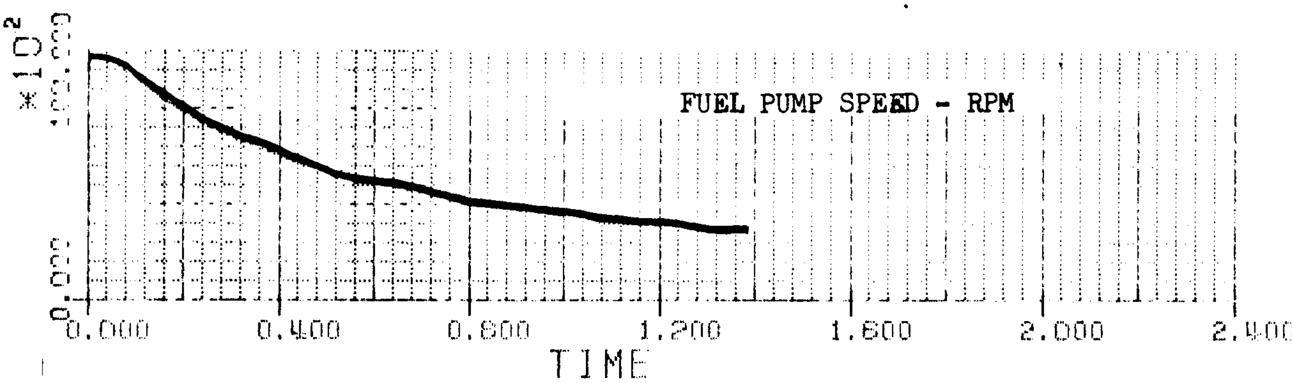
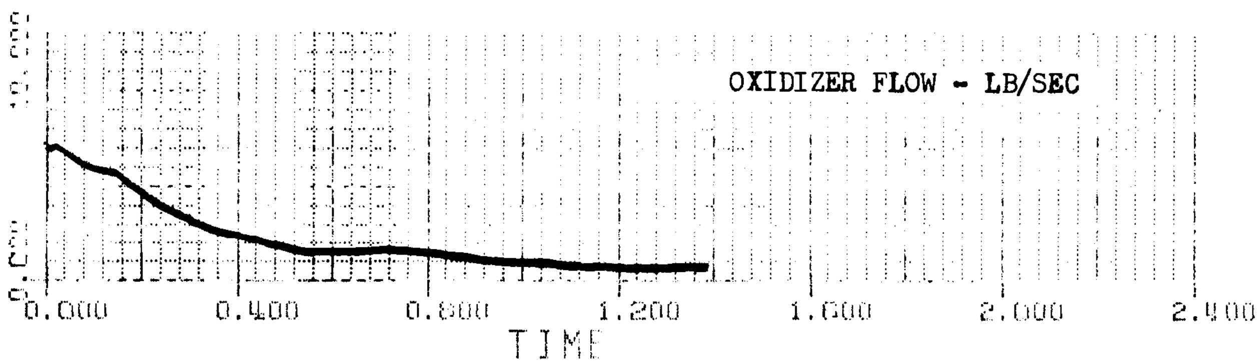
FIGURE III-10







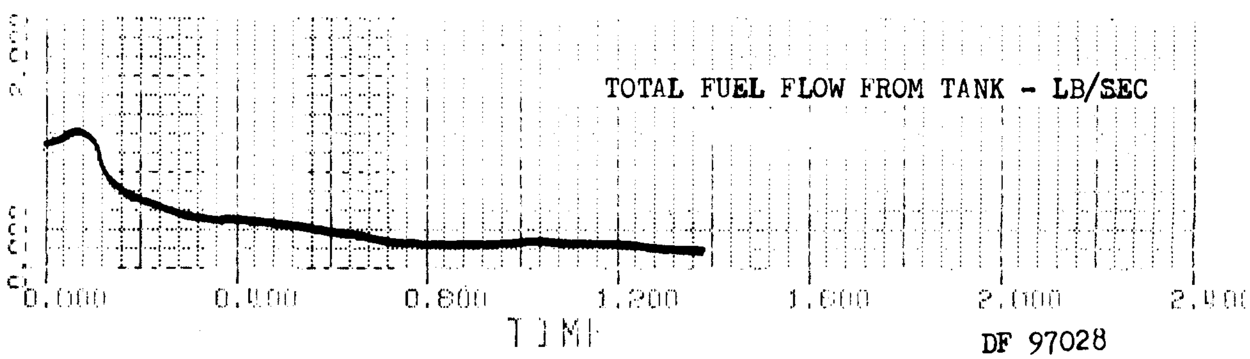


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FIGURE III-10

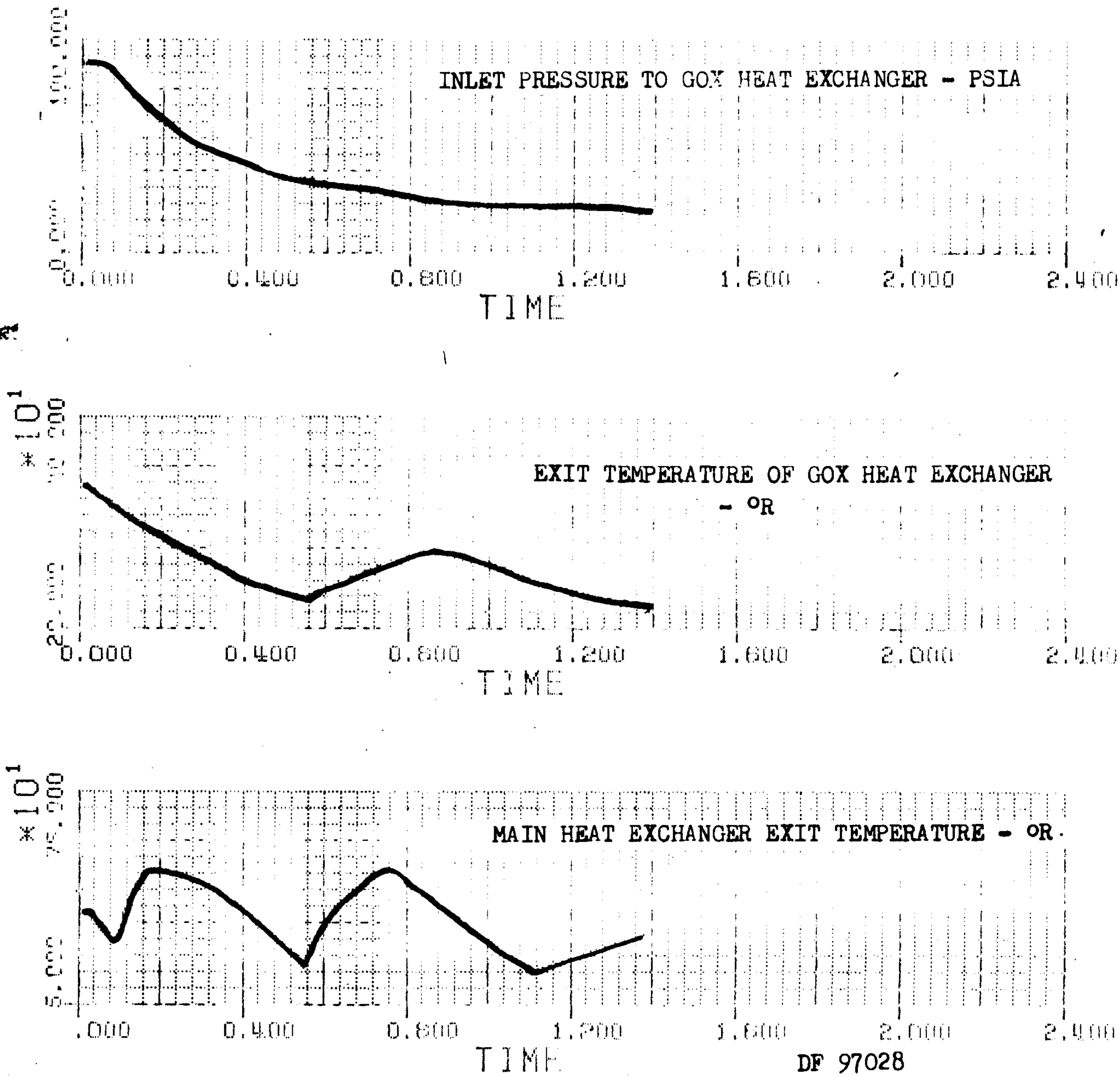

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FIGURE III-10

PRATT & WHITNEY AIRCRAFT

SIMULATED TRANSIENT FROM TANK HEAD IDLE TO MANEUVER THRUST
CATEGORY IV ENGINE

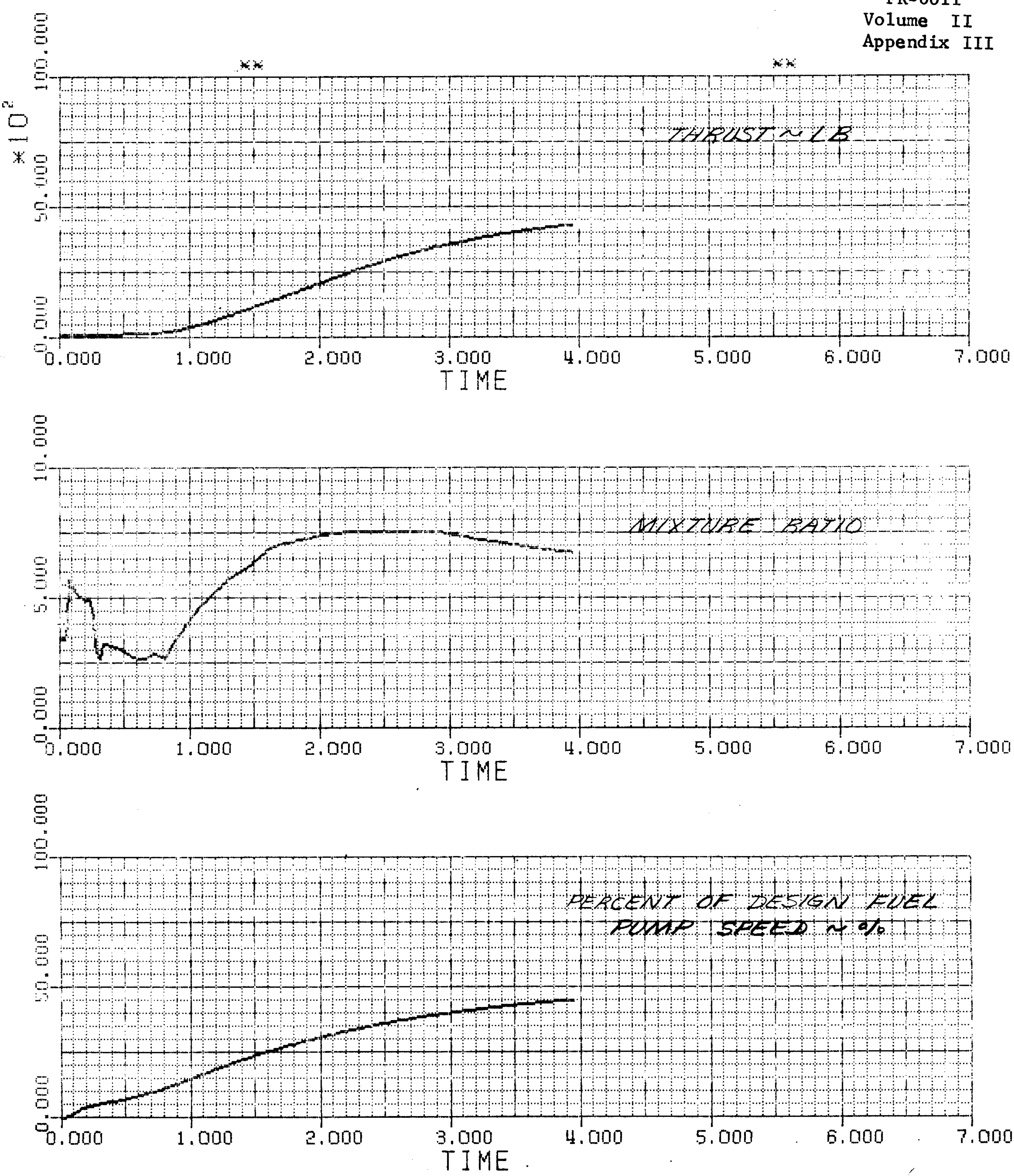

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FIGURE III-11

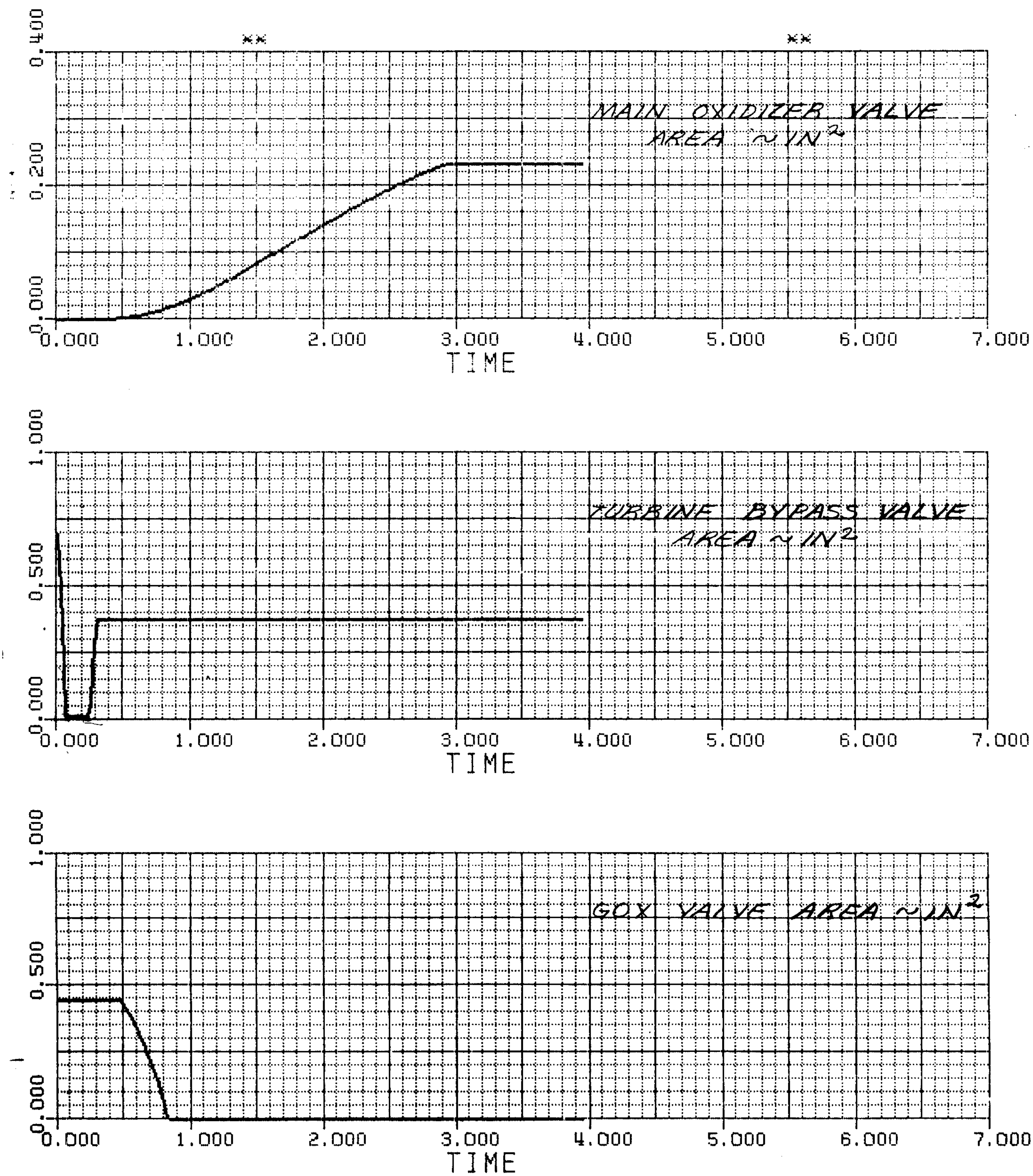

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FIGURE III-11

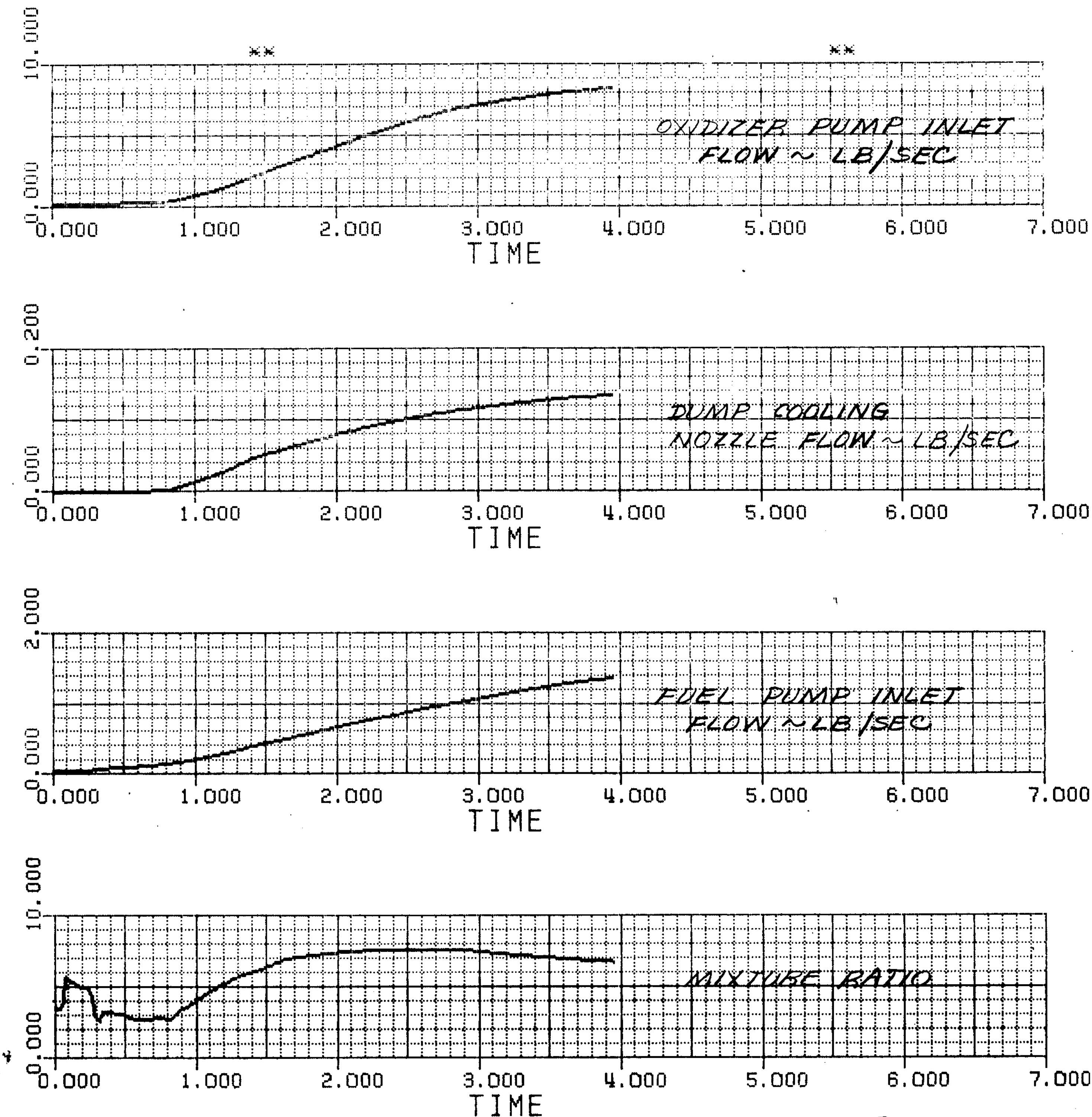

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FIGURE III-11

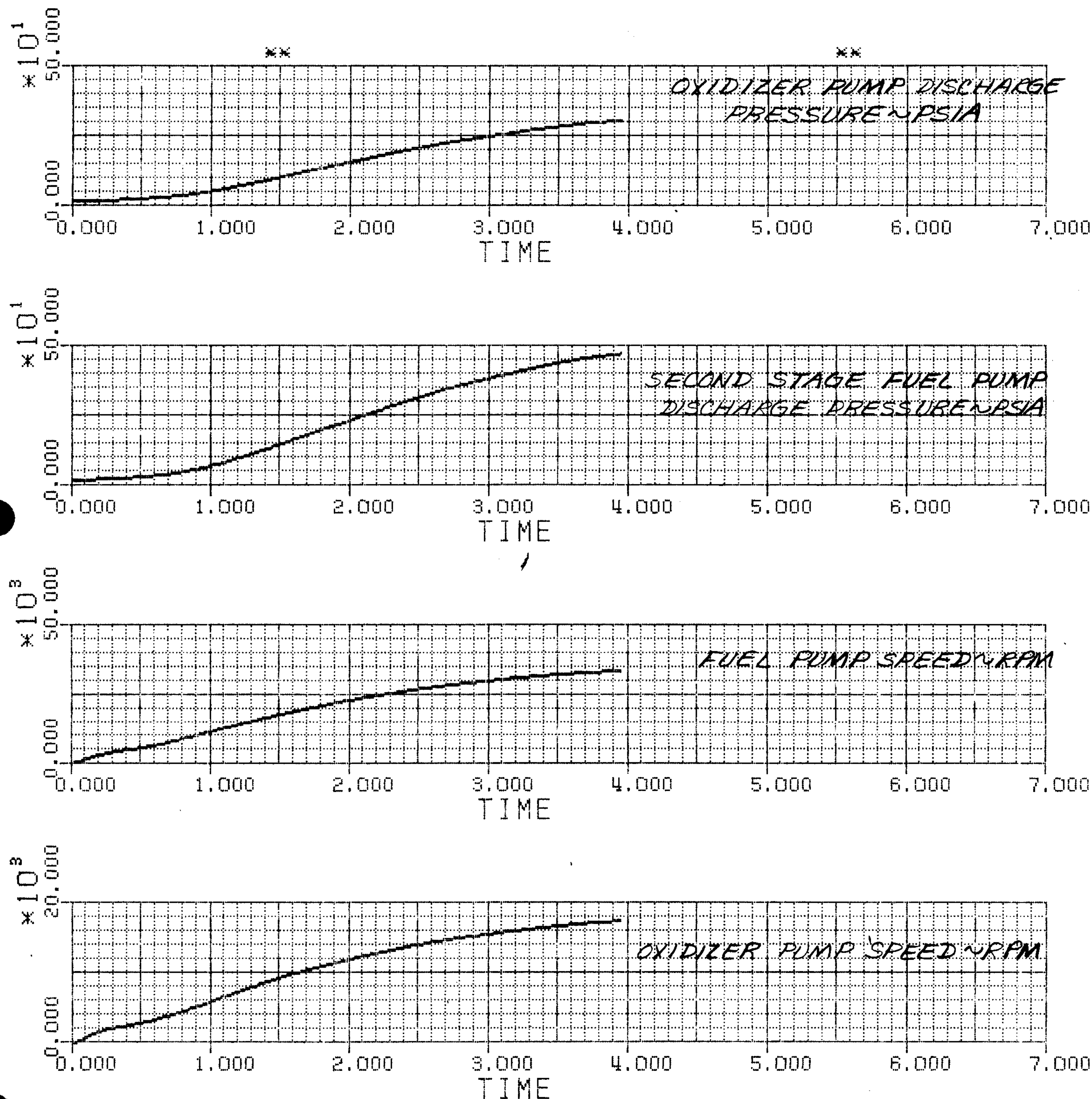

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FIGURE III-11

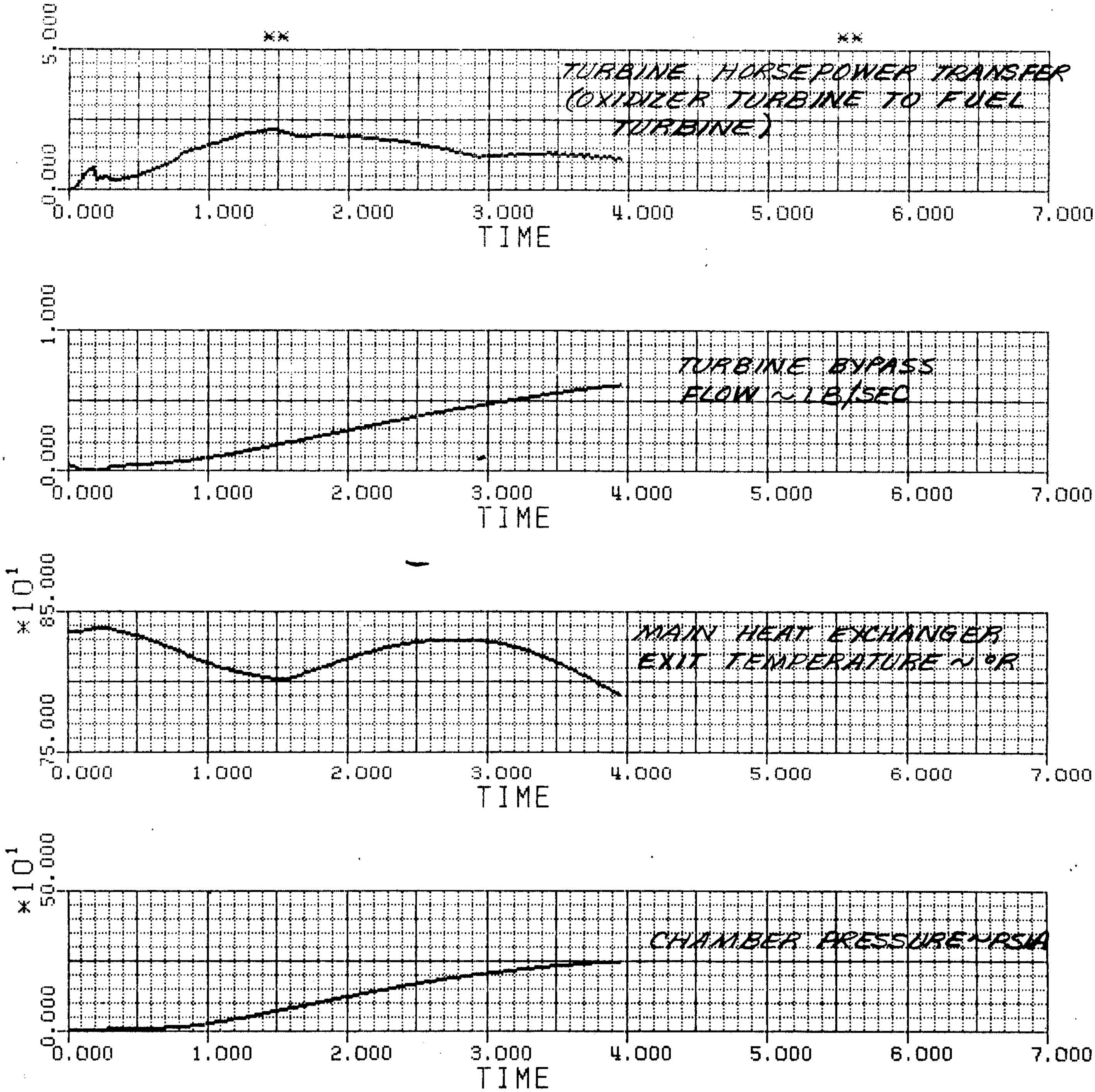

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FIGURE III-11

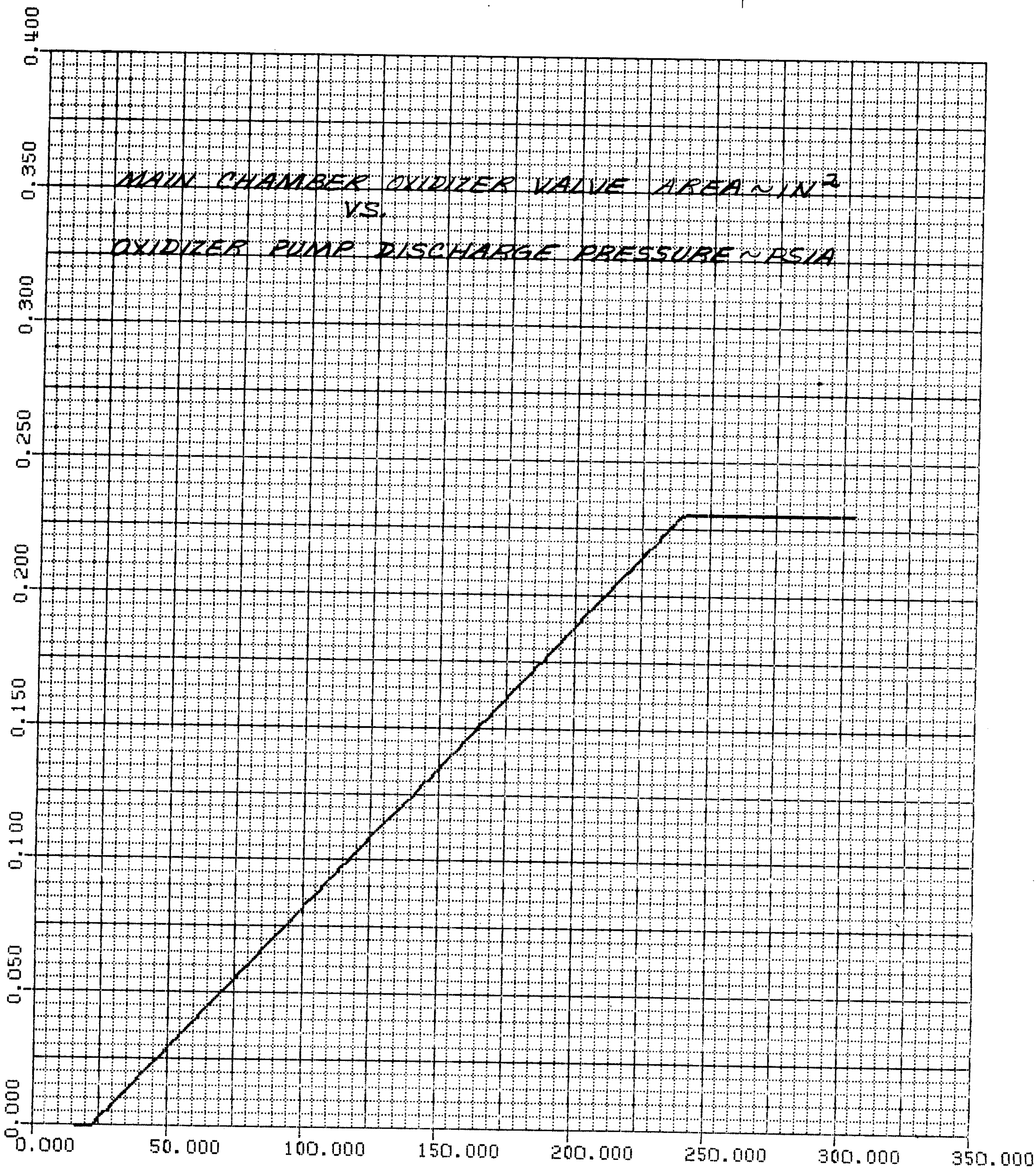

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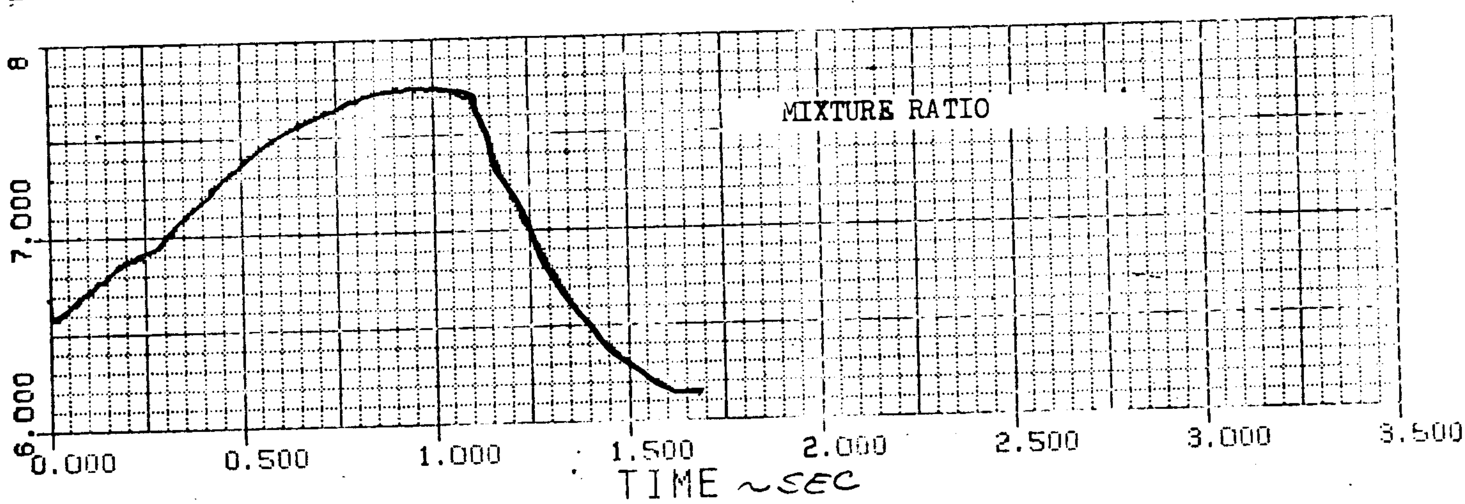
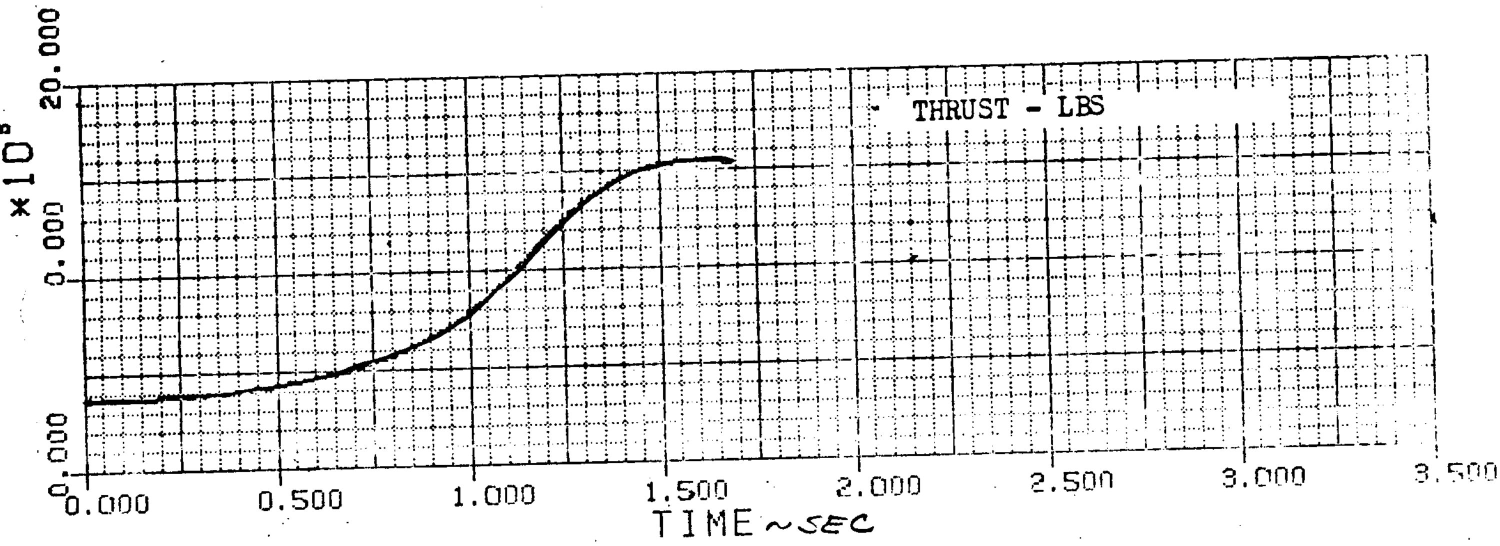
FIGURE III-11

PRATT & WHITNEY AIRCRAFT

SIMULATED START TRANSIENT FROM MANEUVERING THRUST TO FULL THRUST

CATEGORY IV ENGINE





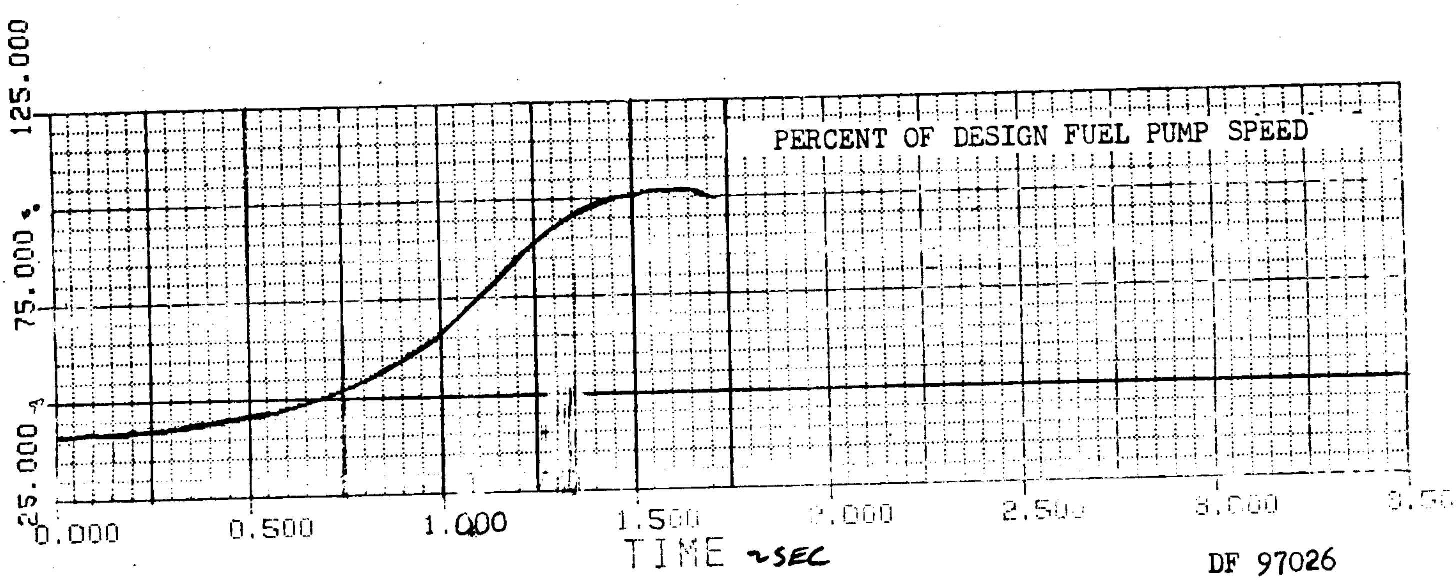


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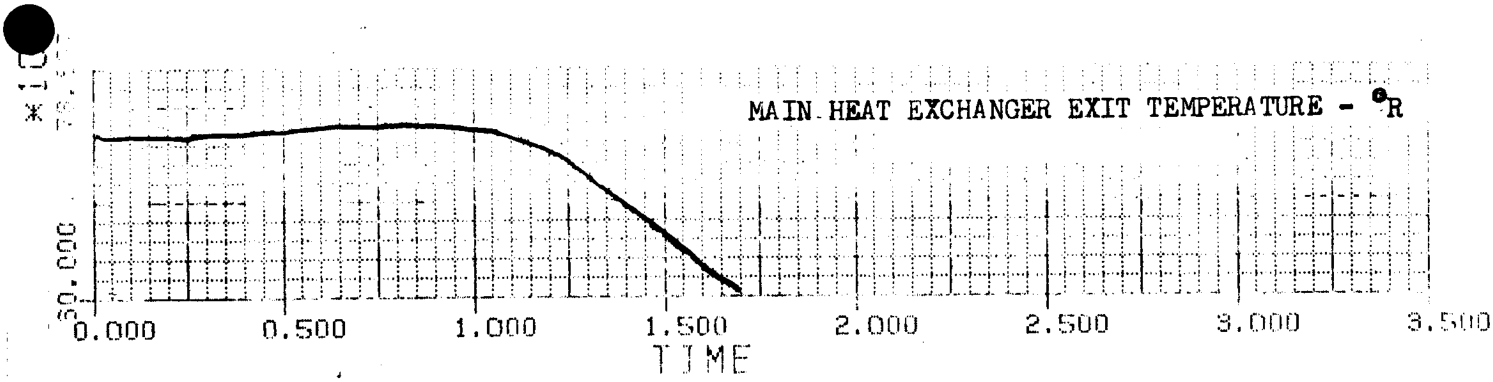
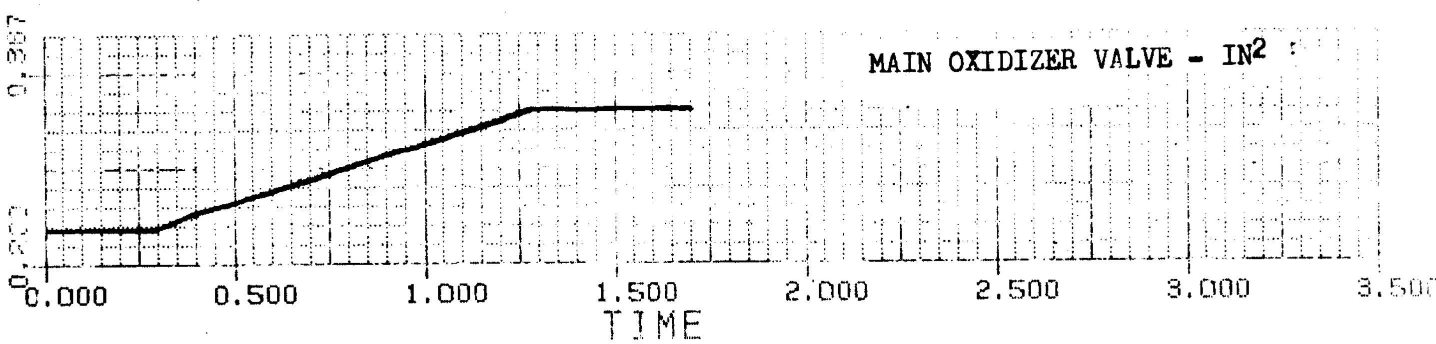
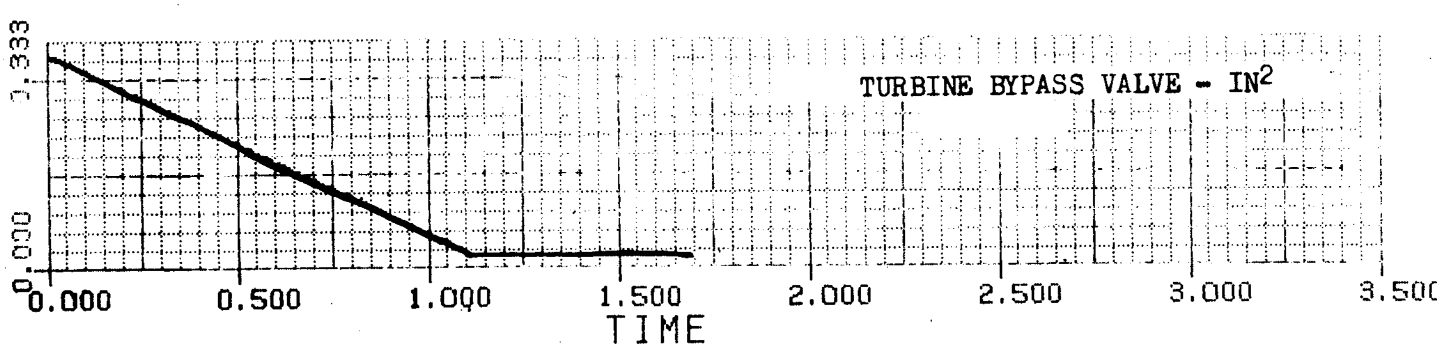
FIGURE III-12







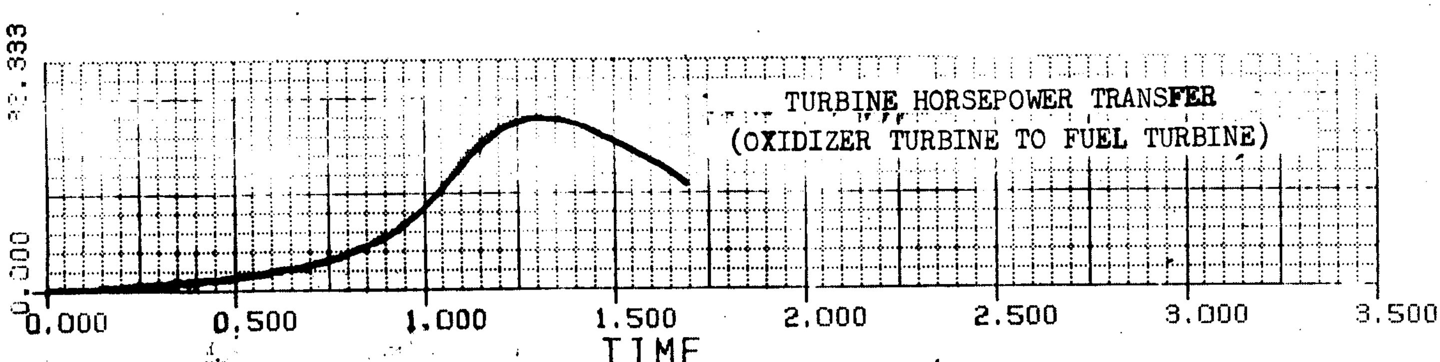


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FIGURE III-12

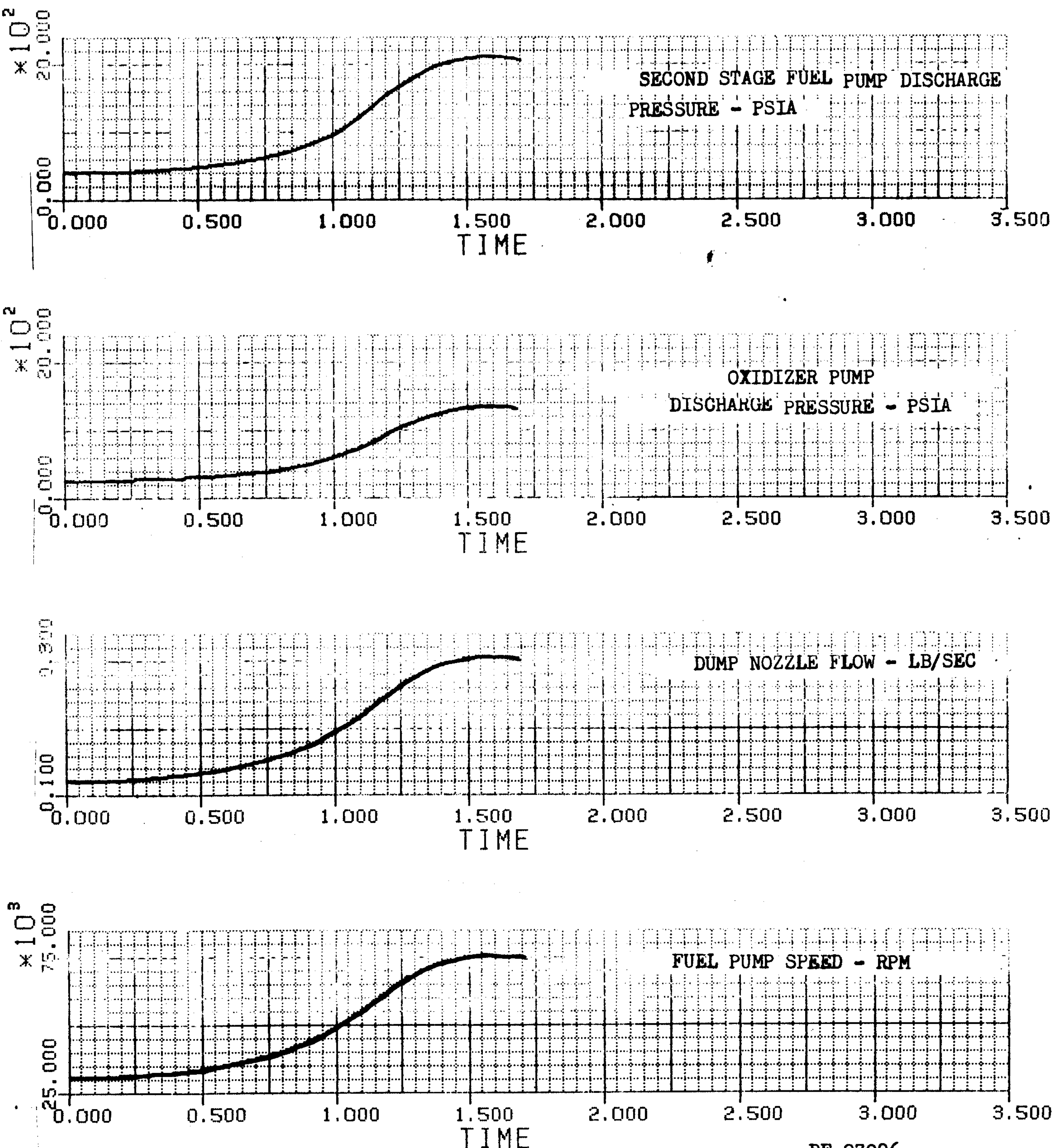

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FIGURE III-12

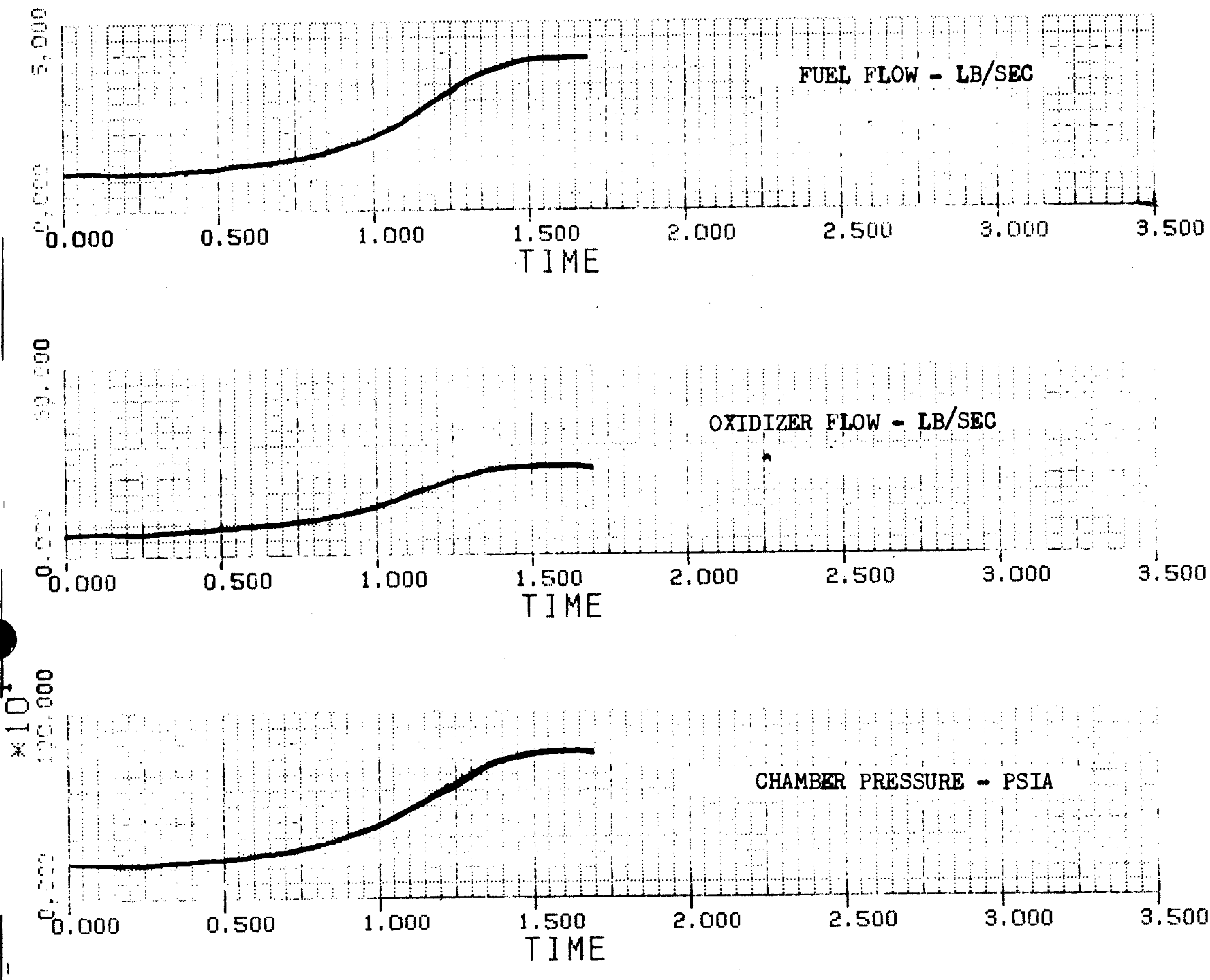

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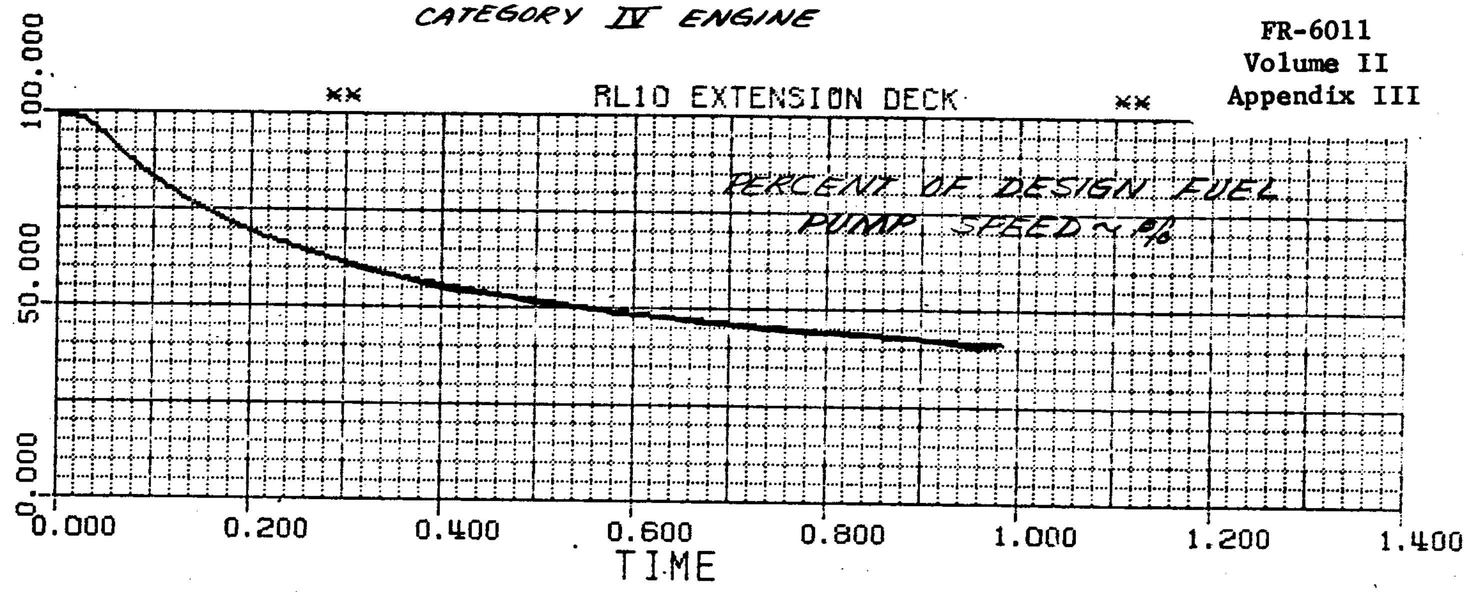
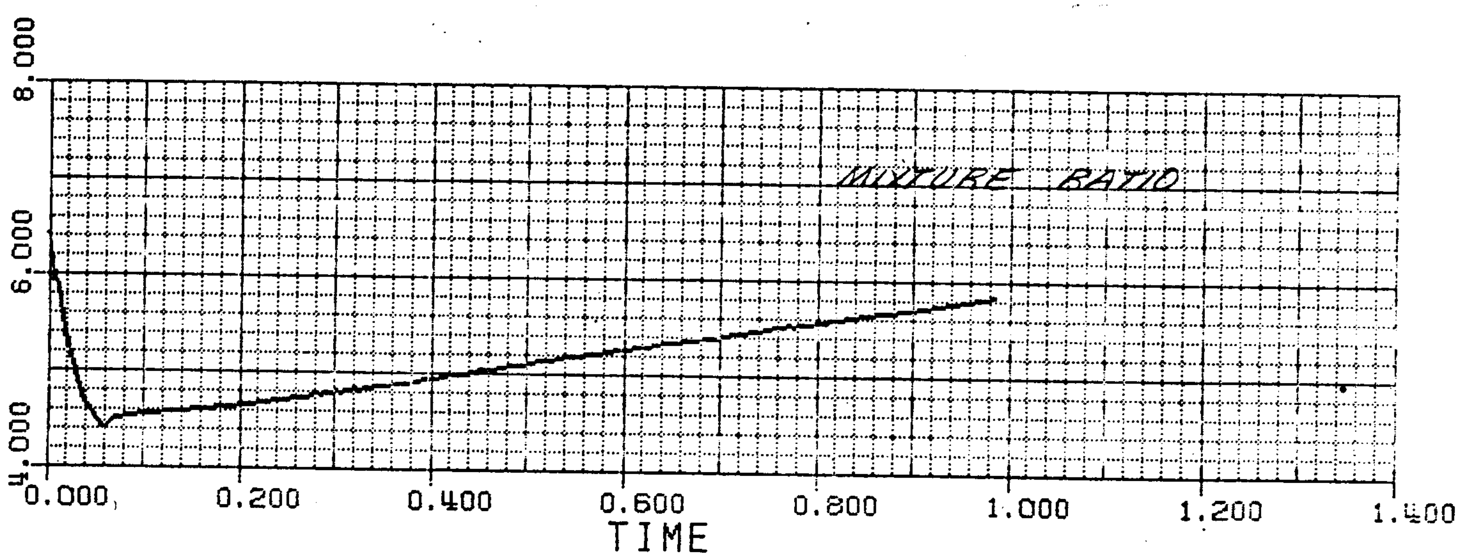
FIGURE III-12

PRATT & WHITNEY AIRCRAFT
SIMULATED TRANSIENT FROM FULL THRUST TO MANEUVER THRUST
CATEGORY IV ENGINE





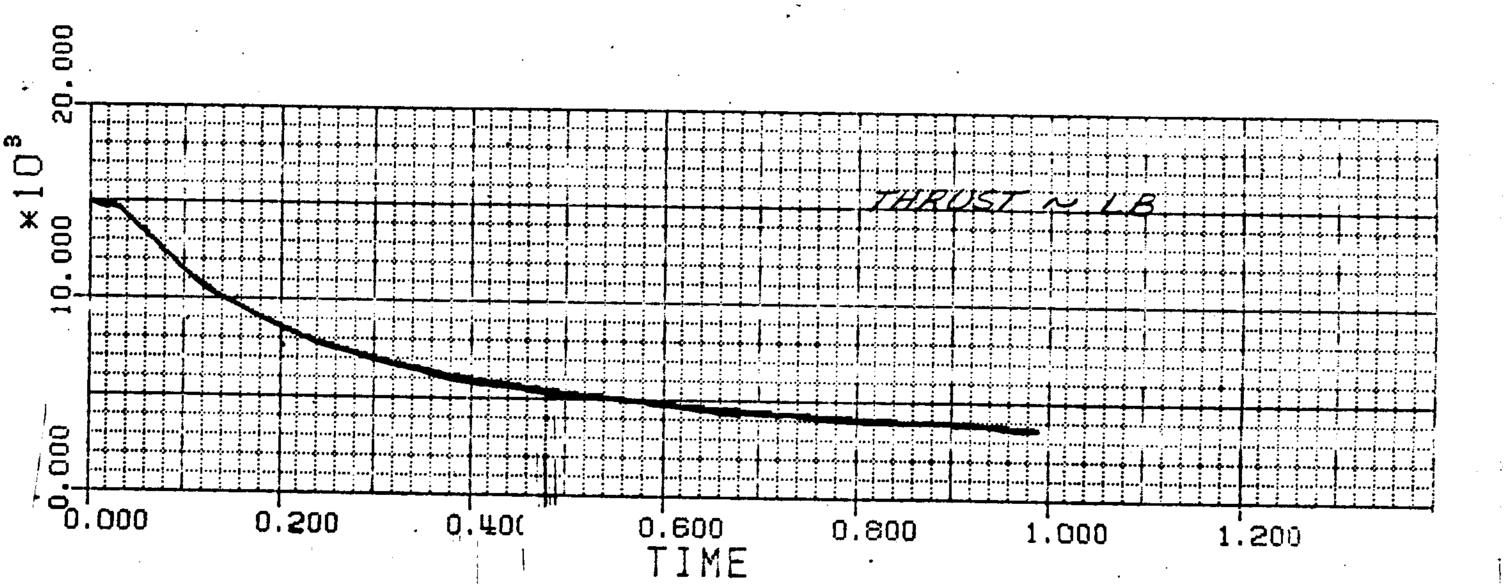


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FIGURE III-13

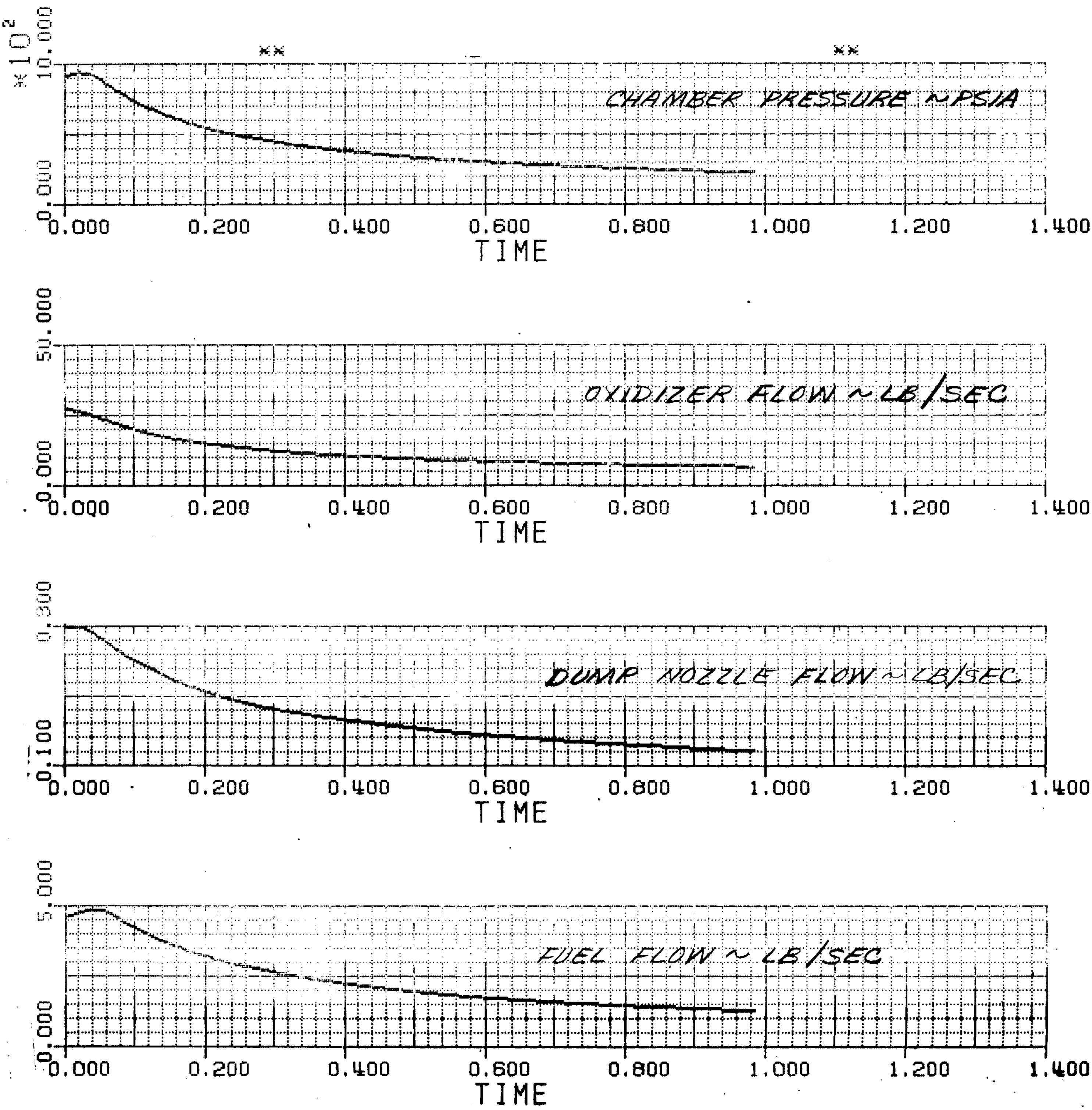

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FIGURE III-13

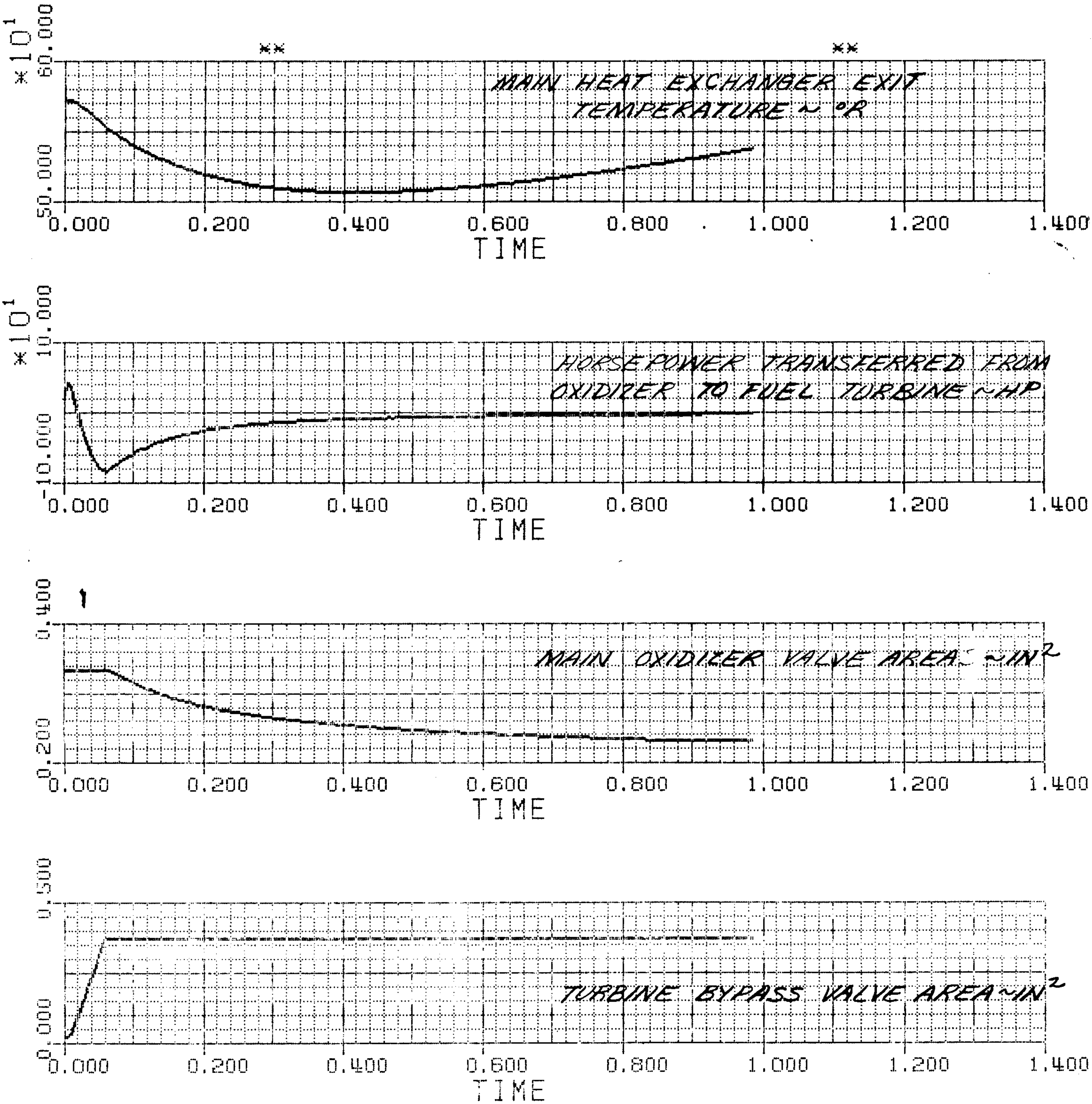

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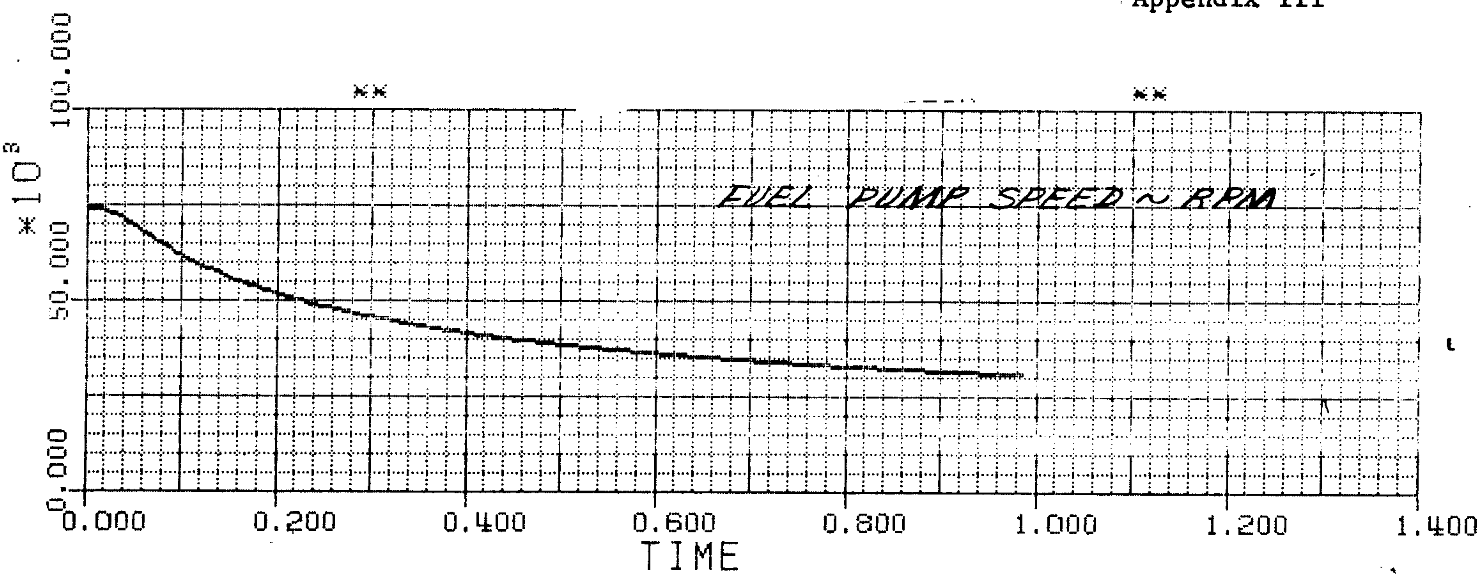
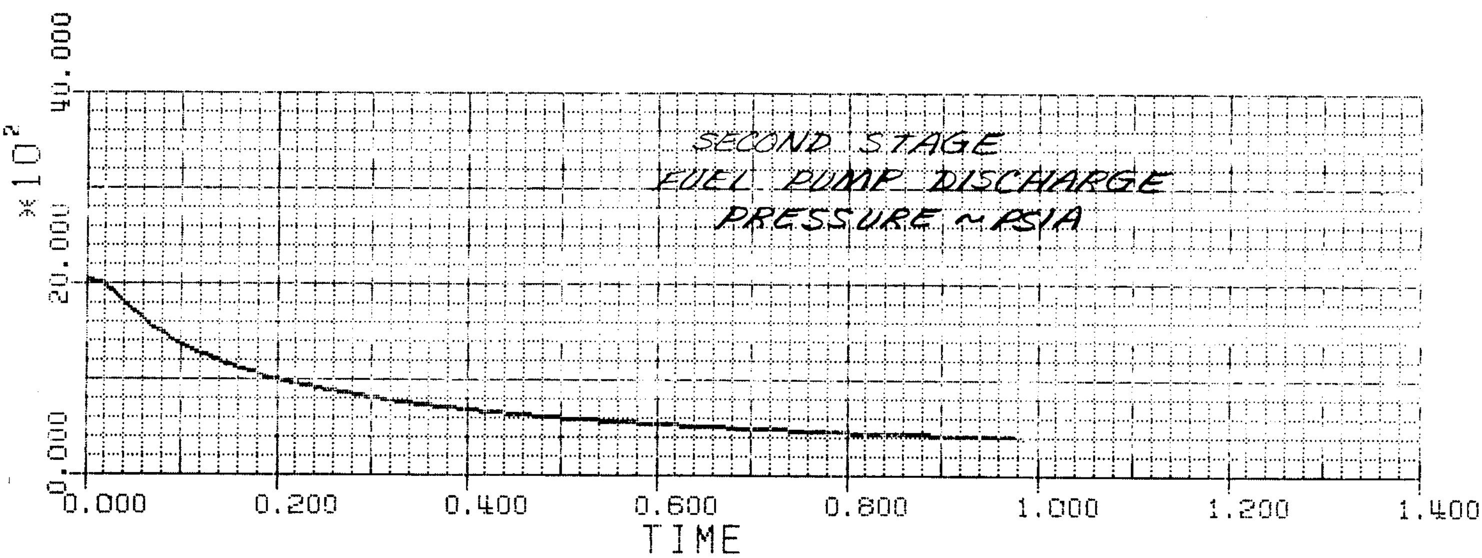
FIGURE III-13





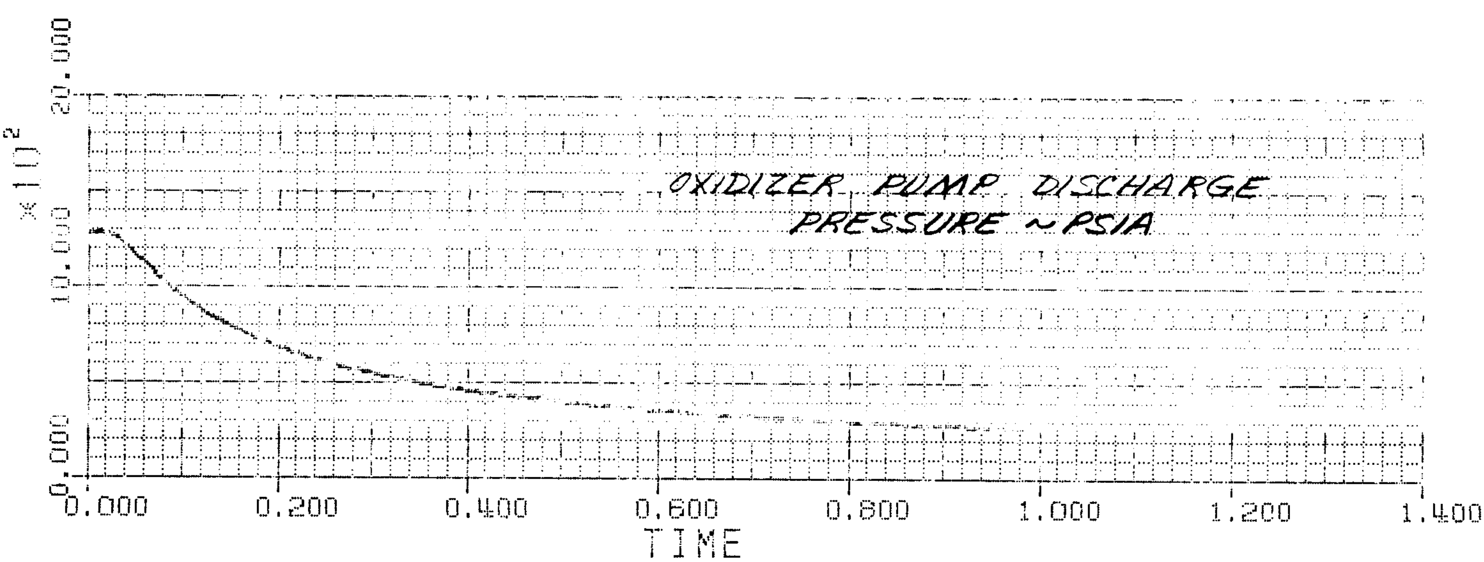


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FIGURE III-13

PRATT & WHITNEY AIRCRAFT

SIMULATED TRANSIENT FROM MANEUVER THRUST TO TANK HEAD IDLE
CATEGORY IV ENGINE

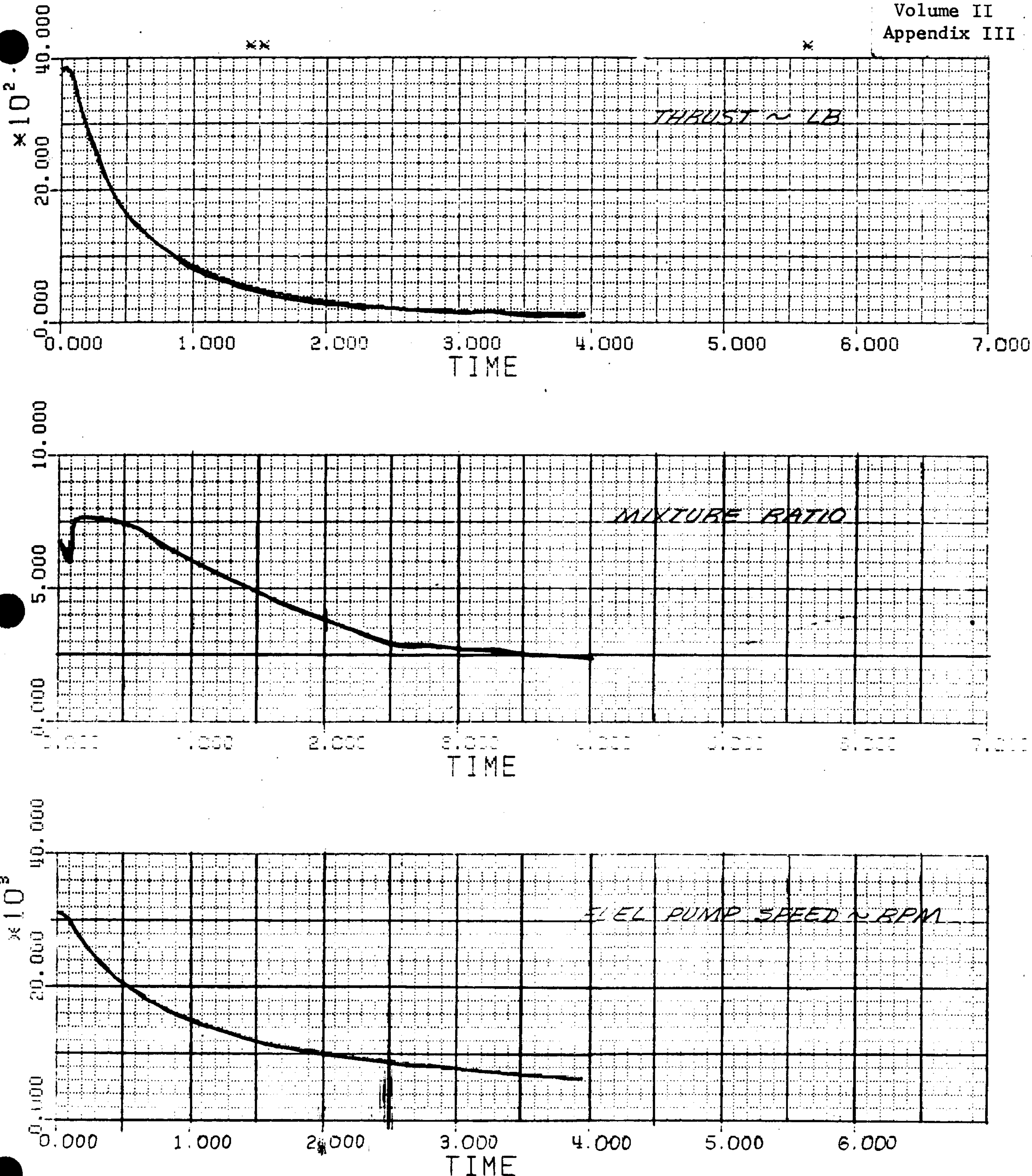

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FIGURE III-14

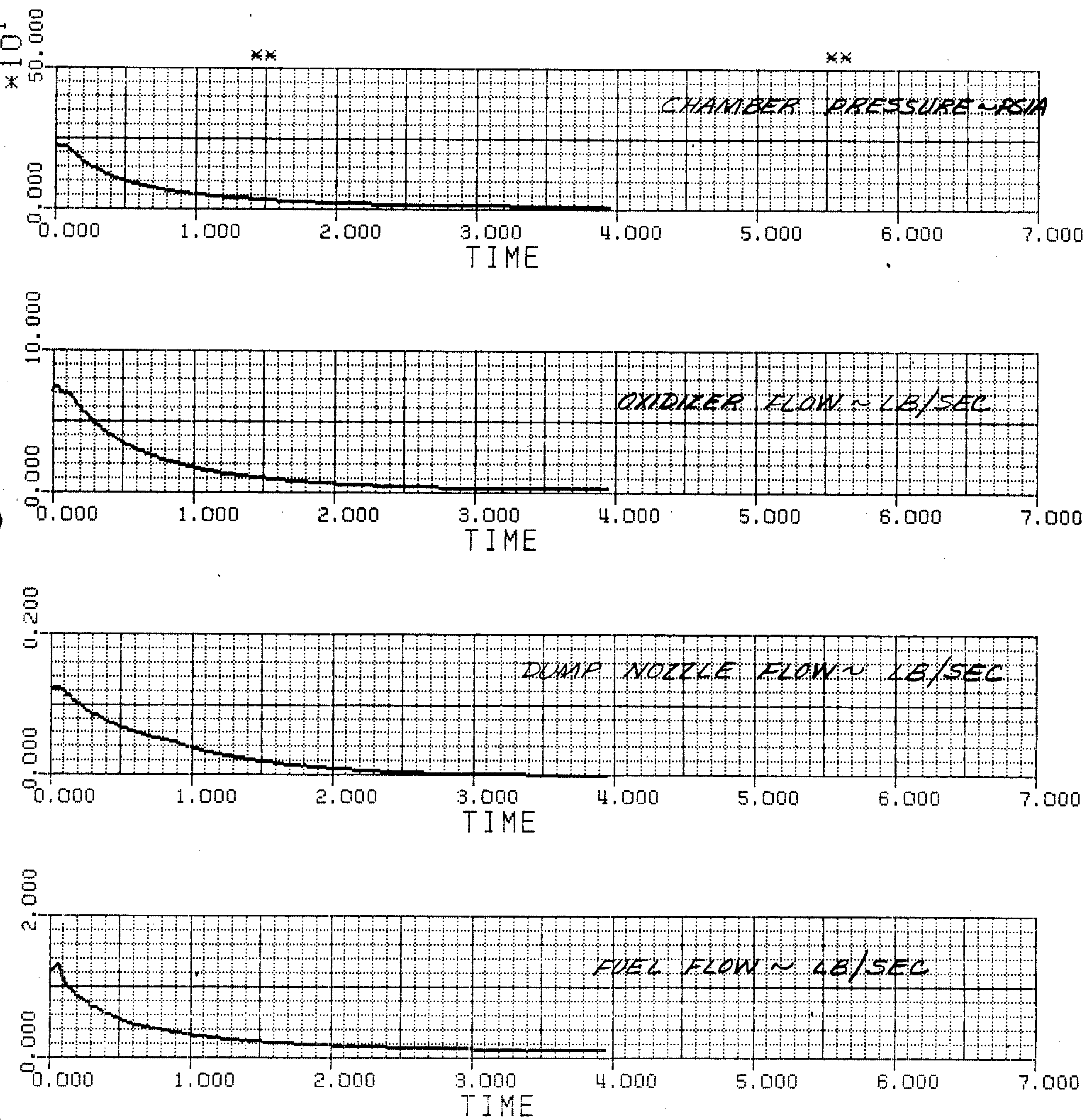

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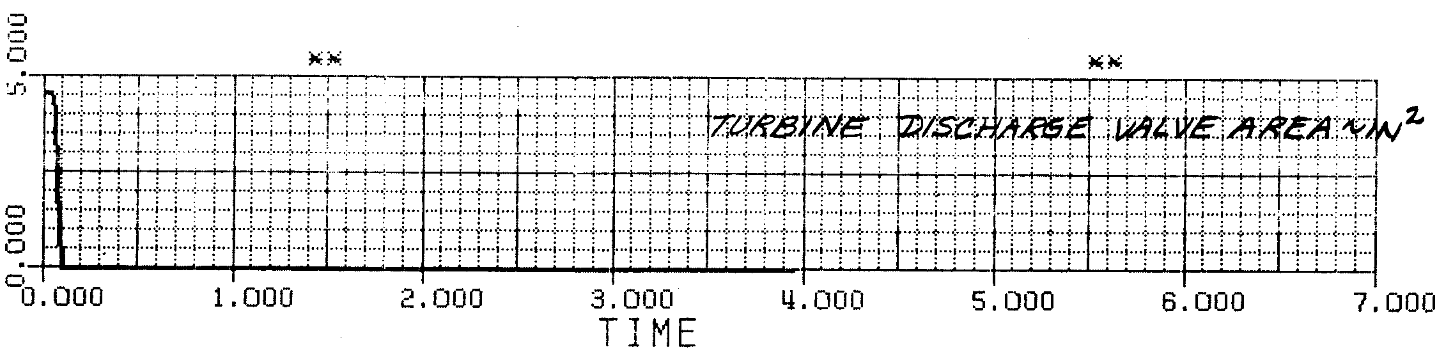
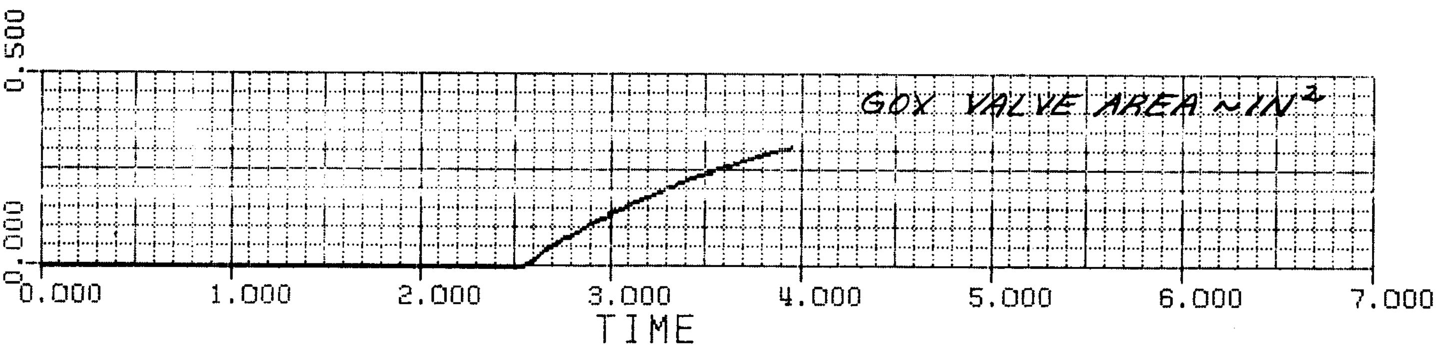
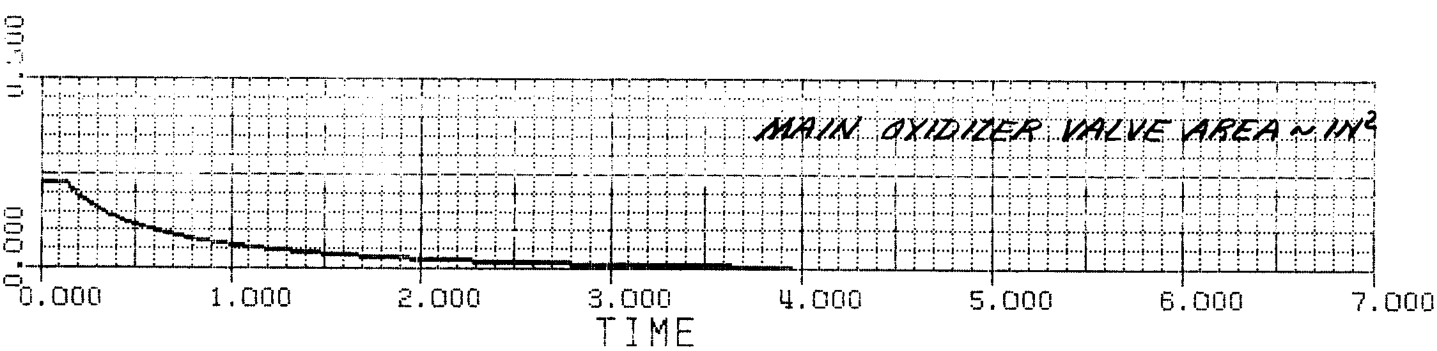
FIGURE III-14







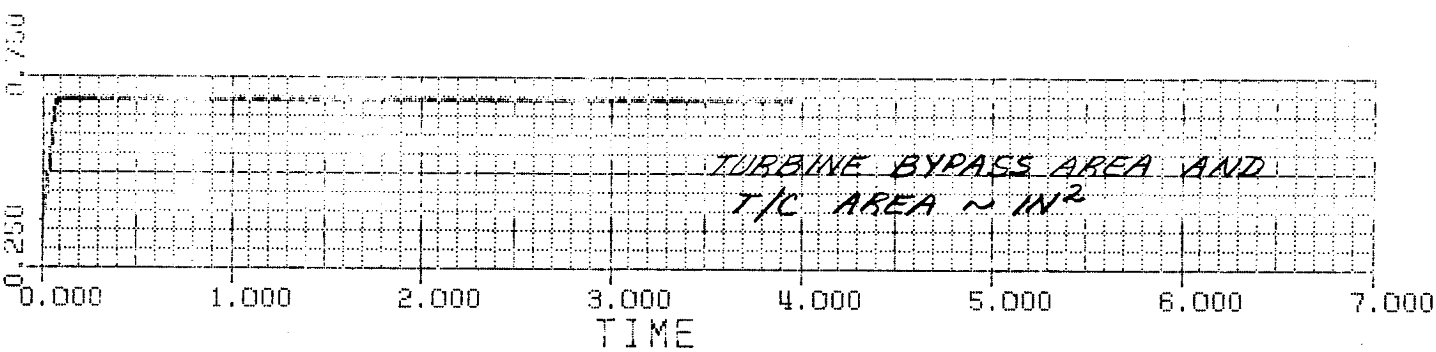


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FIGURE III-14

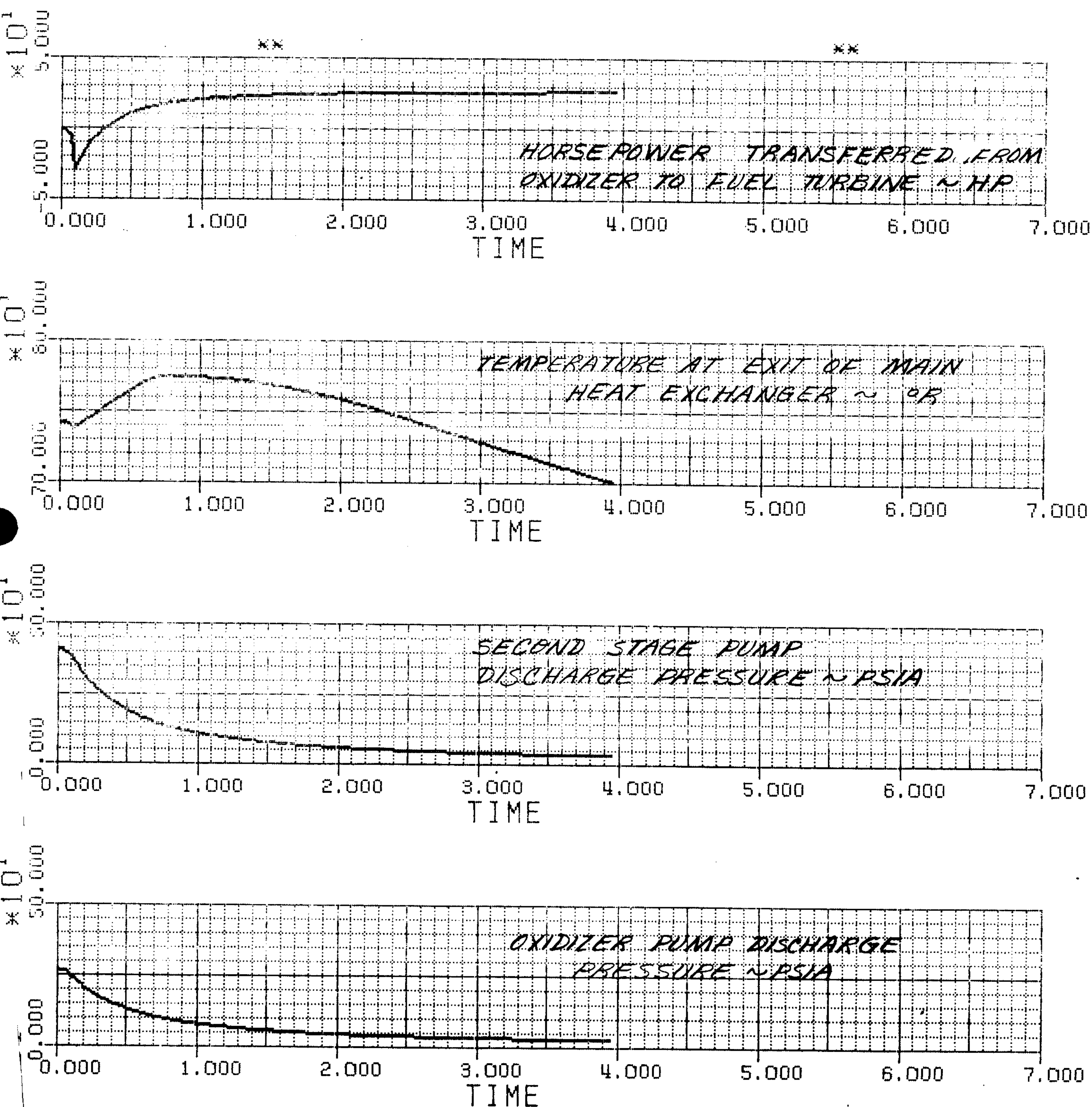

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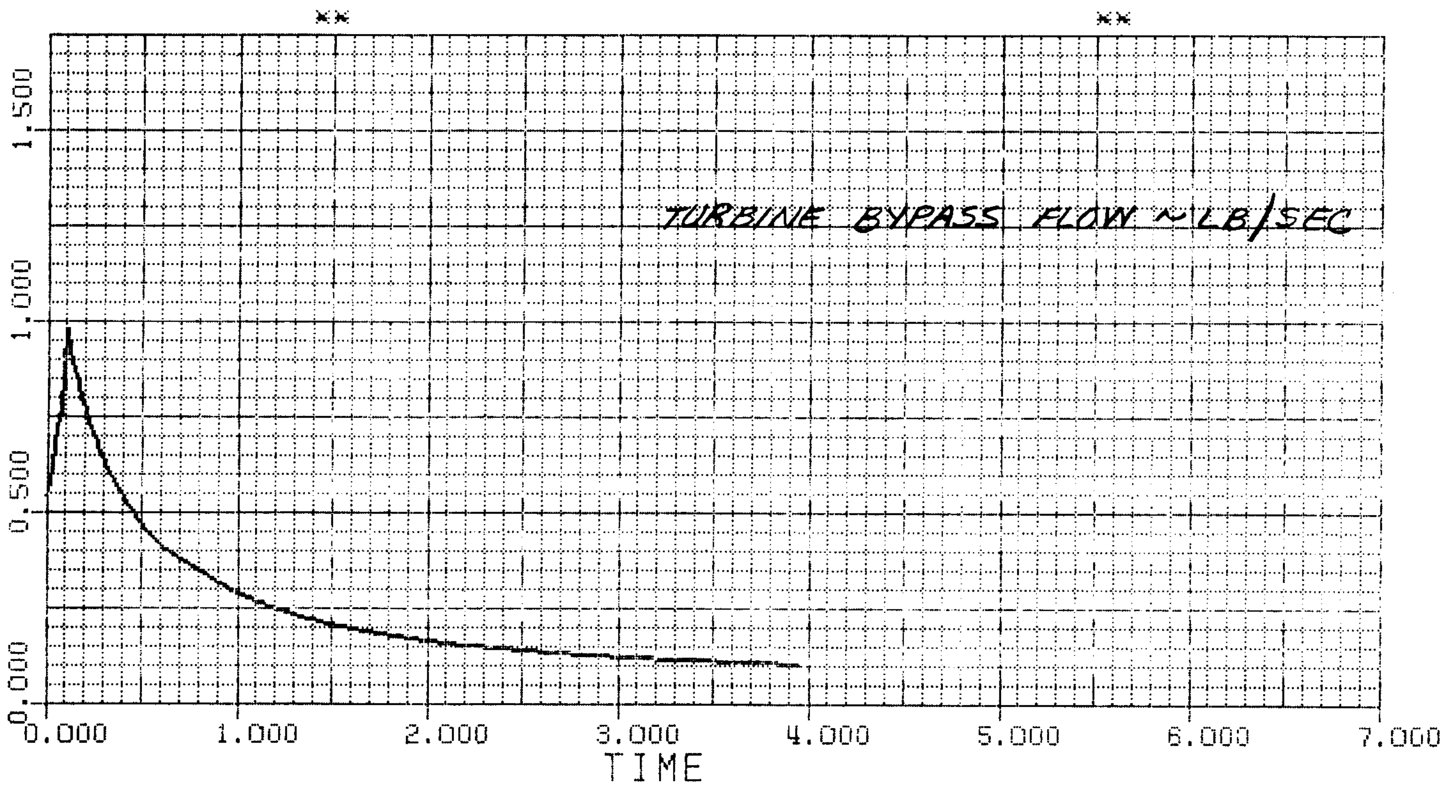
FIGURE III-14



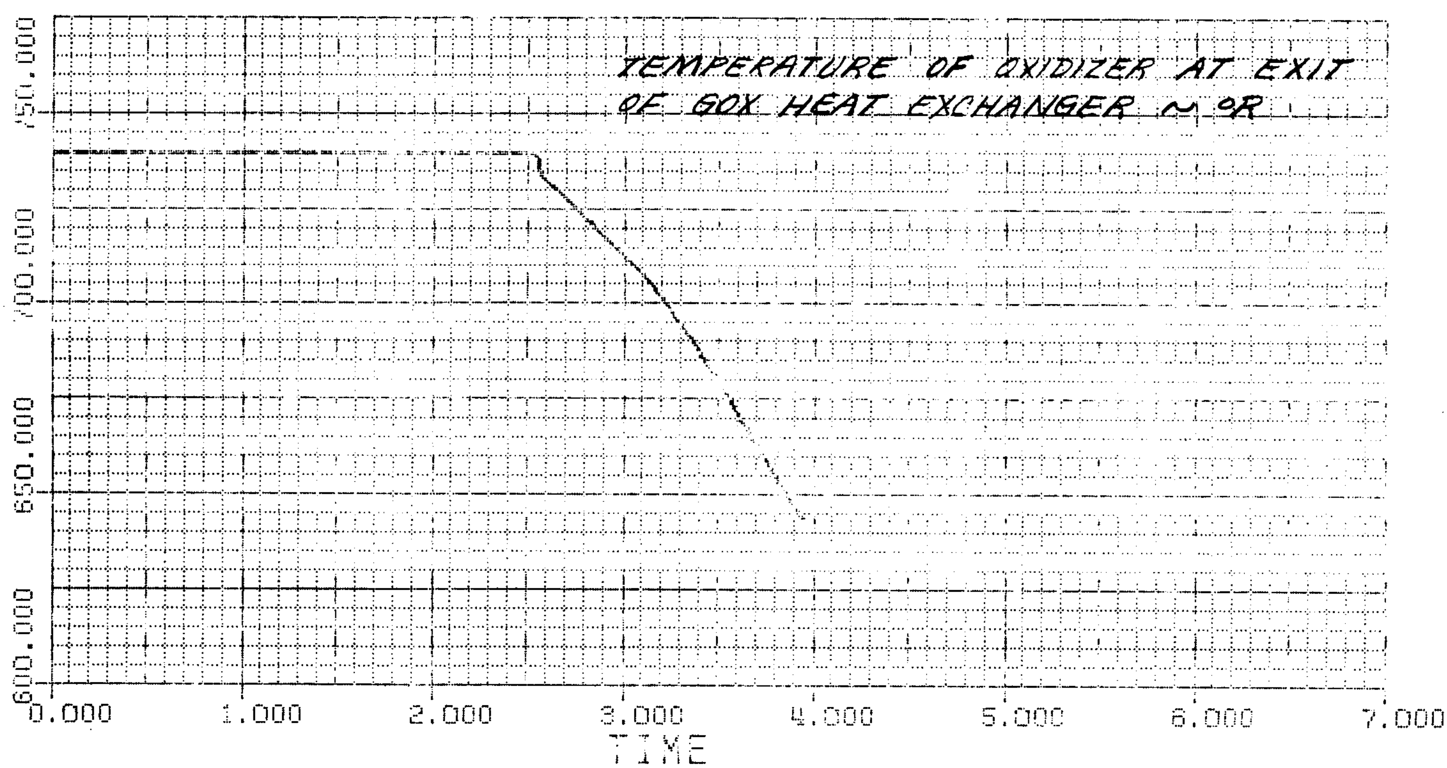


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FIGURE III-14

Appendix IV

Engine Steady State Cycle Calculations

There were four computer programs used during this study to generate steady state engine cycle characteristics. Off-design programs were generated and used for each of the three baseline engines to define off-design operating characteristics. In addition, an expander cycle design point program was used for the Category IV engine to define the optimum design point cycle characteristics. The programs are briefly described below.

1. Off-Design Programs

The three off-design computer cycle programs have similar logic and they all use similar calculation techniques. All of the programs can be balanced in the same three manners. They can be balanced (1) to a particular vacuum thrust and inlet mixture ratio, (2) to a particular oxidizer flow control valve effective area and turbine bypass effective area, and (3) to a particular chamber pressure and oxidizer flow control valve effective area. The first option is used to define characteristics for a particular operating thrust level and mixture ratio. It provides control valve areas to use in running the other options. The second option is used to establish the operating characteristics of the engines when running with fixed control areas. Since the engines operate in maneuvering thrust (pumped idle) with fixed control areas, this option is normally used to determine the effects of inlet pressure variations and/or changes

in tank pressurization flow rates in that operating mode. The third option is used to simulate engine operation at full thrust where chamber pressure is held constant by the thrust control. This option is normally used to evaluate the effects of changing inlet conditions and other variables on engine operation while operating at full thrust.

A schematic of the Derivative IIB engine off-design cycle program is shown in Figure IV-1. It is typical of all of the programs and shows the general operation of the off-design programs.

The pump operating characteristics are simulated in the programs using head coefficient-flow coefficient and efficiency-flow coefficient relationships. The Derivative IIA and IIB characteristics were derived from RL10 pump test data and the Category IV characteristics were obtained from high pressure engine pump test data. The characteristics used in these programs for the main pumps are shown in Figures IV-2 through IV-13.

Turbine efficiency characteristics are used in the simulation as a function of isentropic velocity ratio. The off-design turbine characteristics used for all of the engines were obtained from RL10 turbine rig test data. The characteristics for the Derivative II and Category IV engines are shown in Figure IV-14.

Main chamber and primary nozzle off-design coolant pressure loss and temperature rise characteristics are simulated in the programs using regression equations that calculate ΔP and ΔT characteristics as functions of fuel flow, chamber pressure,

characteristic velocity efficiency, jacket inlet pressure, chamber mixture ratio and chamber combustion temperature. The equations are shown in Table IV-1. They were generated by fitting test data and analytical predictions of chamber-nozzle heat transfer characteristics. Thrust chamber and nozzle performance is calculated in the cycle programs by applying performance loss characteristics obtained from various JANNAF performance programs to JANNAF ODE ideal performance predictions.

Off-design heat transfer characteristics for the gox heat exchanger are simulated in the programs using correlations established for similar heat exchanger configurations. These correlations are for the compact configuration baselined for the engines and they were obtained from work published by W. Kays and A. L. London. The equations used are shown in Table IV-2.

2. Design Point Program

The Category IV design point computer program optimizes all of the components in the engine for a given set of input design conditions. With a given fuel pump speed the program can balance to either a particular fuel pump discharge pressure or a particular chamber pressure level. When it is desired to maximize chamber pressure such as was done for the Category IV engine, the program is run balancing to a particular fuel pump discharge pressure. Different pump discharge pressures are run to determine the maximum obtainable chamber pressure level.

The program was initially set up to optimize the engine design using pump characteristics predicted from Worthington performance predictions and turbine characteristics predicted using the Baljé method. However, as mechanical designs were made of various components the design point performance levels were adjusted to reflect predictions made for the actual components.

3. Baseline Engine Cycle Sheets

Cycle sheets summarizing the values for significant parameters in the engine cycles were generated for each of the baseline engines using the off-design computer programs. Cycle sheets were generated at full thrust for mixture ratios of 5.5, 6.0 and 6.5 and at the design points for maneuvering thrust (pumped idle) and tank head idle. These cycle characteristics are for the baseline engines operating with nominal inlet conditions and no tank pressurization flows. As shown in the Interface Control Document (Volume III of this report) the effects of tank pressurization flows on the engines operating characteristics are small. The baseline engine cycle sheets are shown in Figures IV-15 through IV-29.

In addition to the above, cycle sheets are included in this Appendix for the Category I engine. These cycle sheets are for full thrust operation at mixture ratios of 5.5, 6.0 and 6.5 with no tank pressurization flow. They are shown in Figures IV-30 through IV-32.

Table IV-1

Main Chamber and Primary Nozzle Heat Transfer Predictions Derivative II and Category IV Engines

The following equations are used to predict the off-design main chamber and primary nozzle coolant temperature rise and pressure loss characteristics:

$$\Delta T = \frac{K1 \times RPC^{0.214} \times RPIN^{0.005} \times RECS^{1.951} \times RTC^{2.427}}{RRM^{1.153} \times RWF^{0.436}}$$

$$\Delta P = \left[JFIP - \left(JFIP^{2} - \left(\frac{WFC}{WFCD}\right)^{2} \times \left(\frac{TAVG}{TAVGD}\right) \times PAVGD \times PD \times 2 \right)^{0.5} \right] \times 1.73$$

where: ΔT = coolant temperature rise at off-design point

ΔP = coolant pressure loss at off-design point

K1 = constant to set design point level

RPC = $\dfrac{\text{Chamber pressure}}{19.}$

RPIN = $\dfrac{\text{Inlet Pressure Of Coolant}}{70.}$

RECS = $\dfrac{\eta c^{*}}{0.94}$

RTC = $\dfrac{\text{Combustion Temperature}}{7147.}$

RRM = $\dfrac{\text{Chamber Mixture Ratio}}{5.0}$

RWF = $\dfrac{\text{Coolant Flow Rate}}{0.298}$

JFIP = Coolant Inlet Pressure

WFCD = Coolant Flow Rate At Engine Design Point

TAVGD = Average Temperature Of Coolant In Jacket At Engine Design Point

PAVGD = Average Pressure of Coolant In Jacket At Engine Design Point

ΔPD = Coolant Pressure Loss At Engine Design Point

WFC = Coolant Flow Rate At Off-Design Point

TAVG = Average Temperature Of Coolant In Jacket At Off-Design Point

Table IV-2

Oxygen Heat Exchanger

Heat Transfer Predictions

Derivative II and Category IV Engines

The following equations are used to predict off-design gox heat exchanger heat transfer characteristics in the off-design cycle programs:

C_{min} = Lowest of Cp_O X W_O or Cp_F X W_F

C_{max} = Highest of Cp_O X W_O or Cp_F X W_F

UA = Overall Heat Transfer Coefficient Times Surface Area

$$XNTU = \frac{UA}{C_{min}}$$

$$\text{Effectiveness} = f\left(\frac{C_{min}}{C_{max}}, XNTU\right) \text{ from curve}$$

Heat Flux = Effectiveness X (TFIN-TOIN) X C_{min}

Reference: Kays, W. and London, A. L., <u>Compact Heat Exchangers</u>, McGraw-Hill, New York, 1964.

DERIVATIVE II B OFF-DESIGN COMPUTER PROGRAM CYCLE SCHEMATIC

COMMON INPUT

IVAC GUESS	RPM GUESS
FPIP	WPC GUESS
FNPSP	% BYPASS GUESS
OPIP	OPTION:
ONPSP	(1) BALANCE ON FOI → RPM
AFI	BALANCE ON RMI → WPC
AOI	(2) BALANCE ON BPACDI → RPM
ARN	BALANCE ON ACDOCI → RMI
WOTP	(3) BALANCE ON PCI → RPM
WFTP	BALANCE ON ACDOCI → RMI

INPUT OPTION 1	INPUT OPTION 2	INPUT OPTION 3
FOI	BPACDI	PCI
RMI	ACDOCI	ACDOCI
PC GUESS	FO GUESS	FO GUESS
	RMI GUESS	RMI GUESS
	PC GUESS	

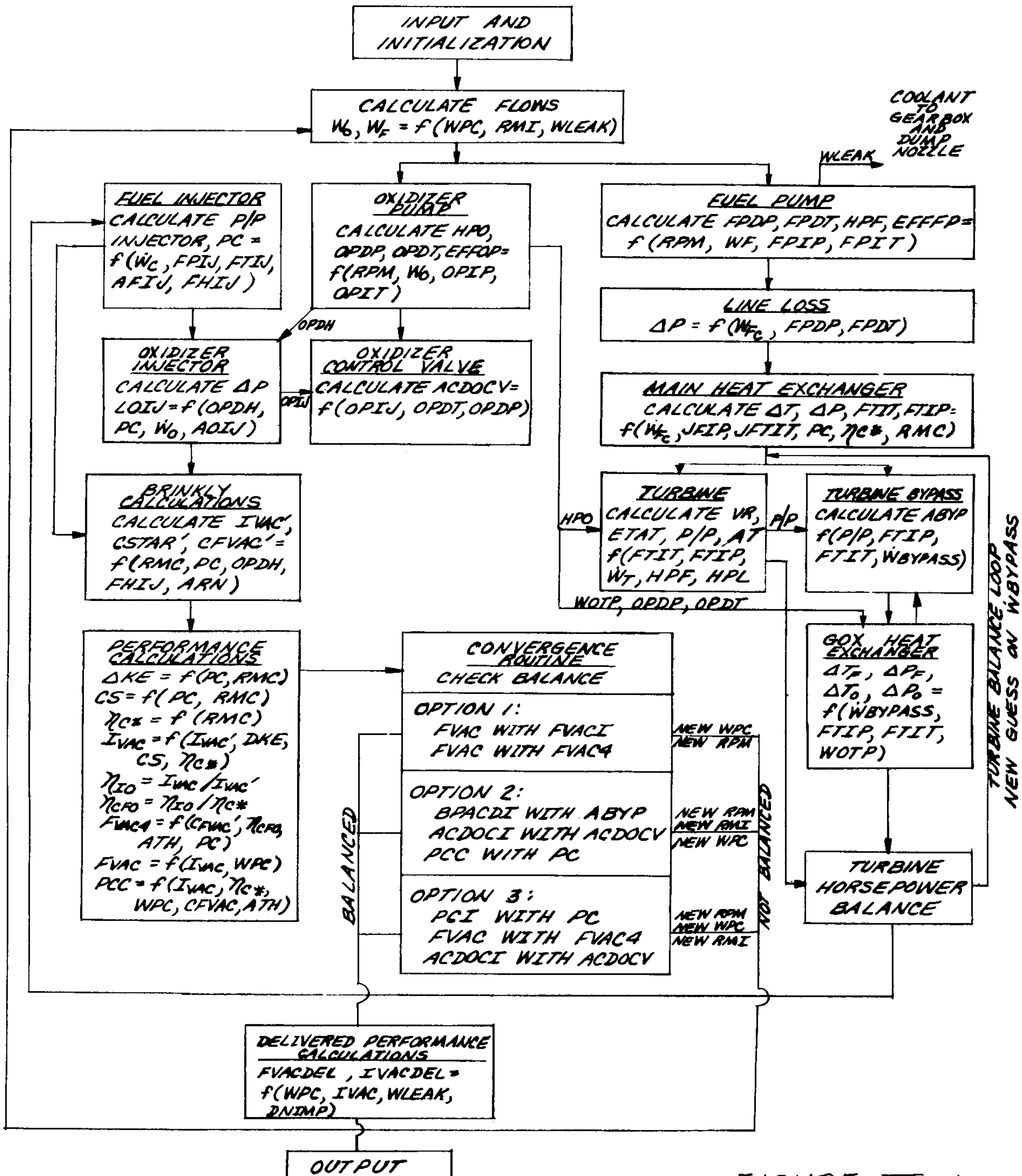

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FIGURE IV-1
SHEET 1 OF 4

DERIVATIVE IIB CYCLE SCHEMATIC NOMENCLATURE

FPIP	Fuel Pump Inlet Pressure
FNPSP	Fuel Pump Inlet Net Positive Suction Pressure
OPIP	Oxidizer Pump Inlet Pressure
ONPSP	Oxidizer Pump Inlet Net Positive Suction Pressure
AFI	Fuel Injector Area
AOI	Oxidizer Injector Area
ARN	Nozzle Area Ratio
WOTP	Oxidizer Tank Pressurization Flow
WFTP	Fuel Tank Pressurization Flow
RPM	Fuel Pump Speed
WPC	Chamber Propellant Flow
FOI	Input Thrust
RMI	Inlet Mixture Ratio
BPACDI	Input Turbine Bypass Valve Area
ACDOCI	Input Oxidizer Control Valve Area
PCI	Input Chamber Pressure
WLEAK	Coolant Flow to Gearbox and Dump Nozzle
WO	Oxidizer Flowrate
WF	Inlet Fuel Flowrate
FPDP	Fuel Pump Discharge Pressure
FPDT	Fuel Pump Discharge Temperature
HPF	Fuel Pump Horsepower
EFFFP	Fuel Pump Efficiency
FPIT	Fuel Pump Inlet Temperature
WFC	Chamber Fuel Flow
Δ T	Main Heat Exchanger Temperature Rise
Δ P	Main Heat Exchanger Pressure Loss

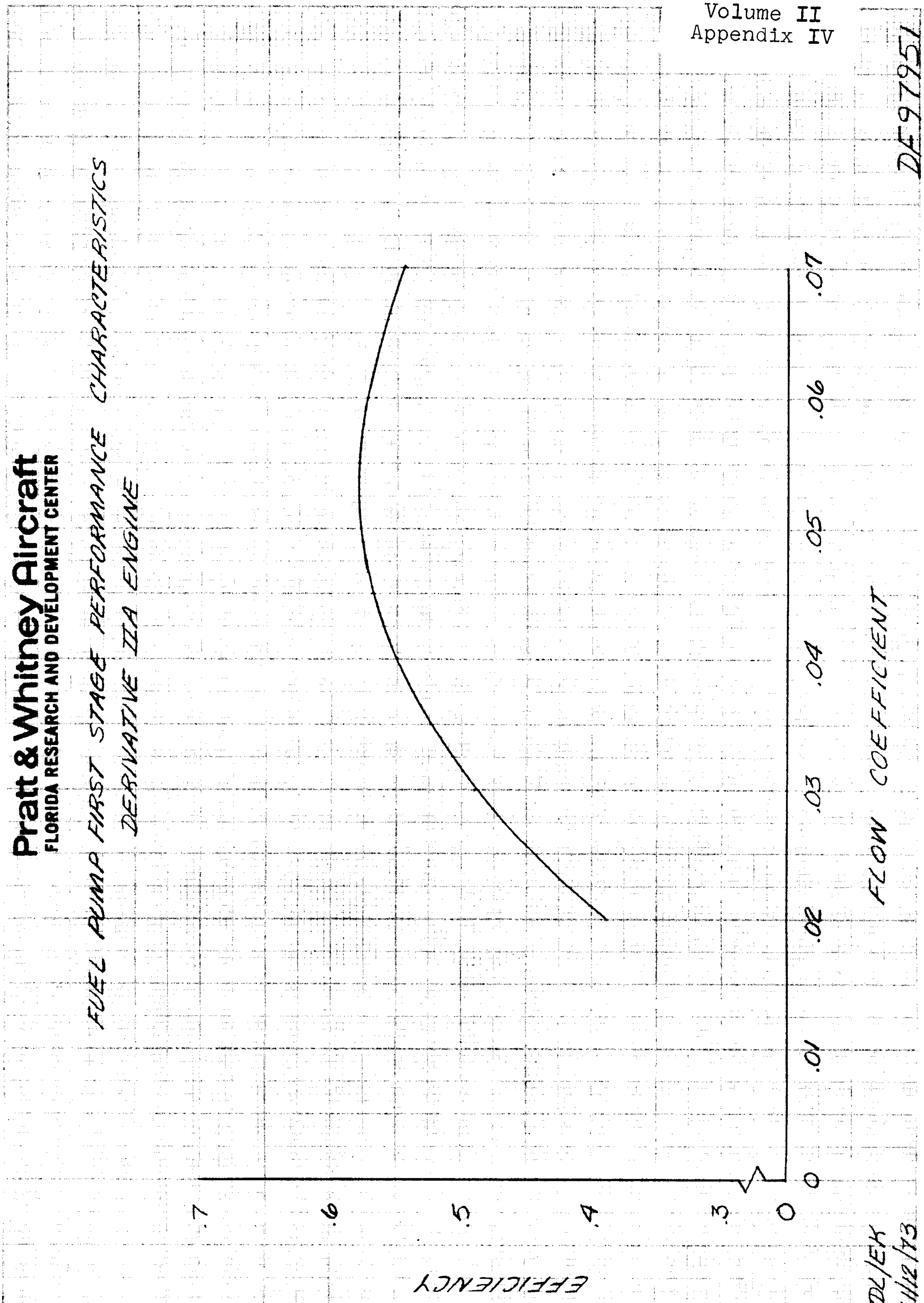
Figure IV-1
Sheet 2 of 4

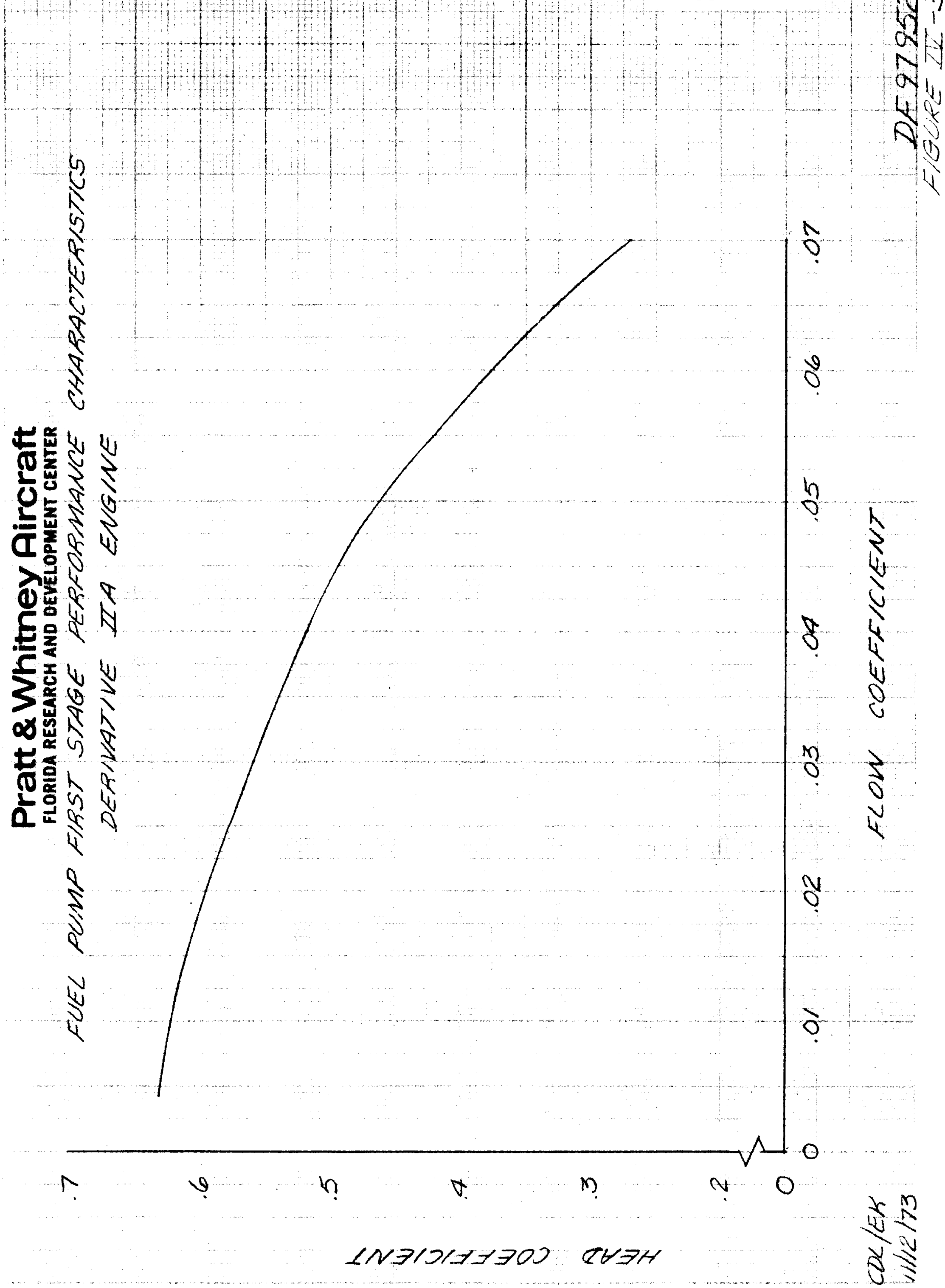
FTIP	Fuel Turbine Inlet Pressure
FTIT	Fuel Turbine Inlet Temperature
JFIP	Jacket Inlet Pressure
JFTIT	Jacket Inlet Temperature
PC	Chamber Pressure
η c*	Characteristic Velocity Efficiency
RMC	Chamber Mixture Ratio
VR	Isentropic Velocity Ratio
ETAT	Turbine Efficiency
P/P	Pressure Ratio
AT	Turbine Area
WT	Turbine Flowrate
ABYP	Bypass Valve Area
W_{bypass}	Bypass Flowrate
FPIJ	Fuel Injector Inlet Pressure
FTIJ	Fuel Injector Inlet Temperature
AFIJ	Fuel Injector Effective Area
FHIJ	Fuel Injector Inlet Enthalpy
ΔPLOIJ	Oxidizer Injector Pressure Loss
OPDH	Oxidizer Pump Discharge Enthalpy
AOIJ	Oxidizer Injector Effective Area
HPO	Oxidizer Pump Horsepower
OPDP	Oxidizer Pump Discharge Pressure
OPDT	Oxidizer Pump Discharge Temperature
EFFOP	Oxidizer Pump Efficiency
OPIT	Oxidizer Pump Inlet Temperature
ACDOCV	Oxidizer Control Valve Effective Area
OPIJ	Oxidizer Injector Inlet Pressure

Figure IV-1
Sheet 3 of 4

IVAC'	Ideal Impulse
CSTAR'	Ideal Characteristic Velocity
CFVAC'	Ideal Thrust Coefficient
Δ KE	Nozzle Kinetic Loss
CS	Nozzle Boundary Layer Loss and Divergence Loss
IVAC	Vacuum Specific Impulse at RMC
η IO	Impulse Efficiency
η CFO	Thrust Coefficient Efficiency
FVAC4	Pseudo Thrust
FVAC	Thrust
DNIMP	Dump Nozzle Impulse
FVACDEL	Delivered Vacuum Thrust
IVACDEL	Delivered Vacuum Impulse

Figure IV-1
Sheet 4 of 4


Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER
FUEL PUMP FIRST STAGE PERFORMANCE CHARACTERISTICS
DERIVATIVE IIA ENGINE
EFFICIENCY
.7
.6
.5
.4
.3
0
0
.01
.02
.03
.04
.05
.06
.07
FLOW COEFFICIENT
CDL/EK
11/12/73
DE97951
FIGURE IV-2


Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER
FUEL PUMP FIRST STAGE PERFORMANCE CHARACTERISTICS
DERIVATIVE IIA ENGINE
HEAD COEFFICIENT
.7
.6
.5
.4
.3
.2
0
FLOW COEFFICIENT
0
.01
.02
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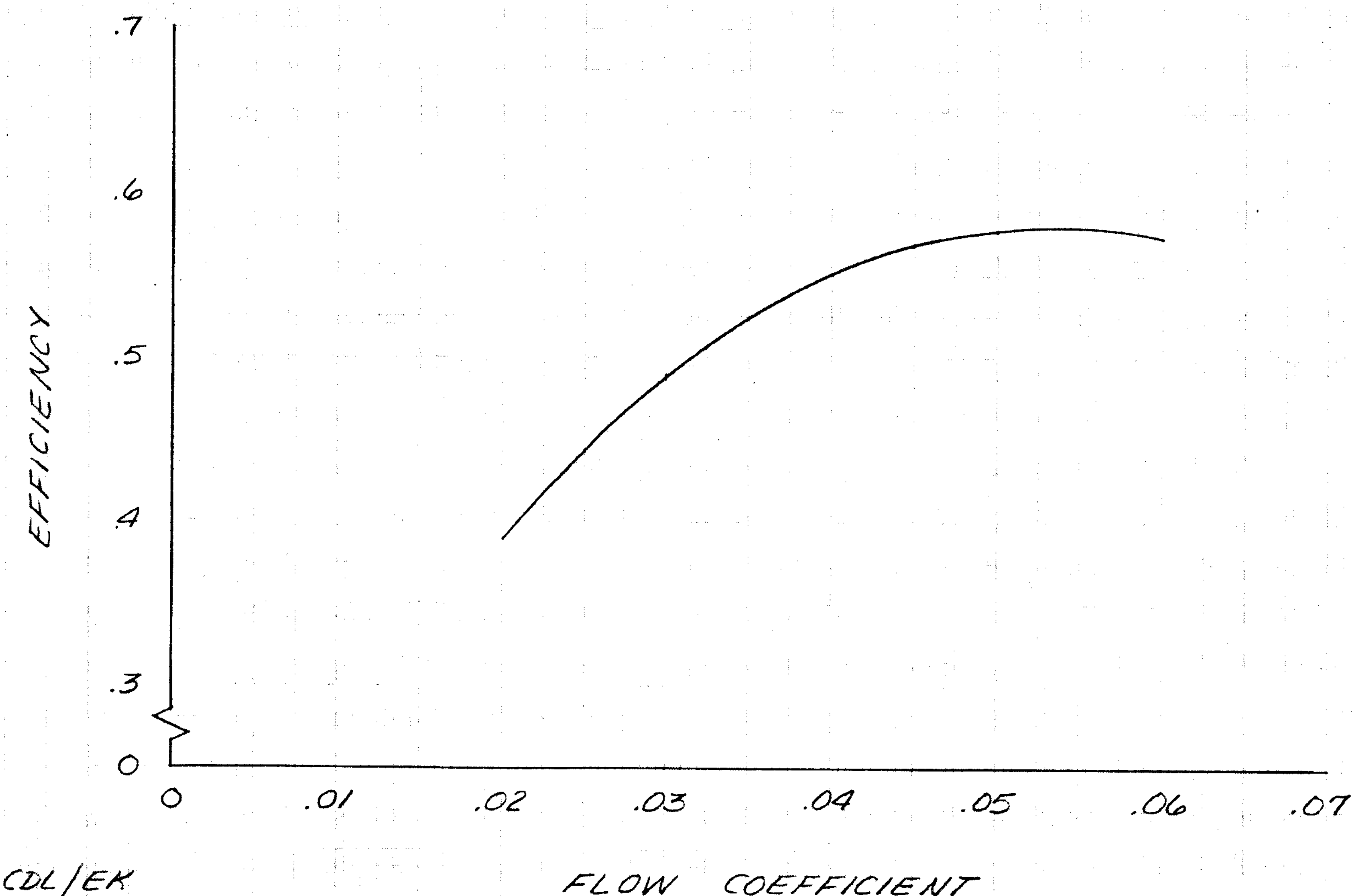
.04
.05
.06
.07
CDL/EK
11/12/73
DF 97952
FIGURE IV-3

Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER

FUEL PUMP FIRST STAGE PERFORMANCE CHARACTERISTICS
DERIVATIVE IIB ENGINE



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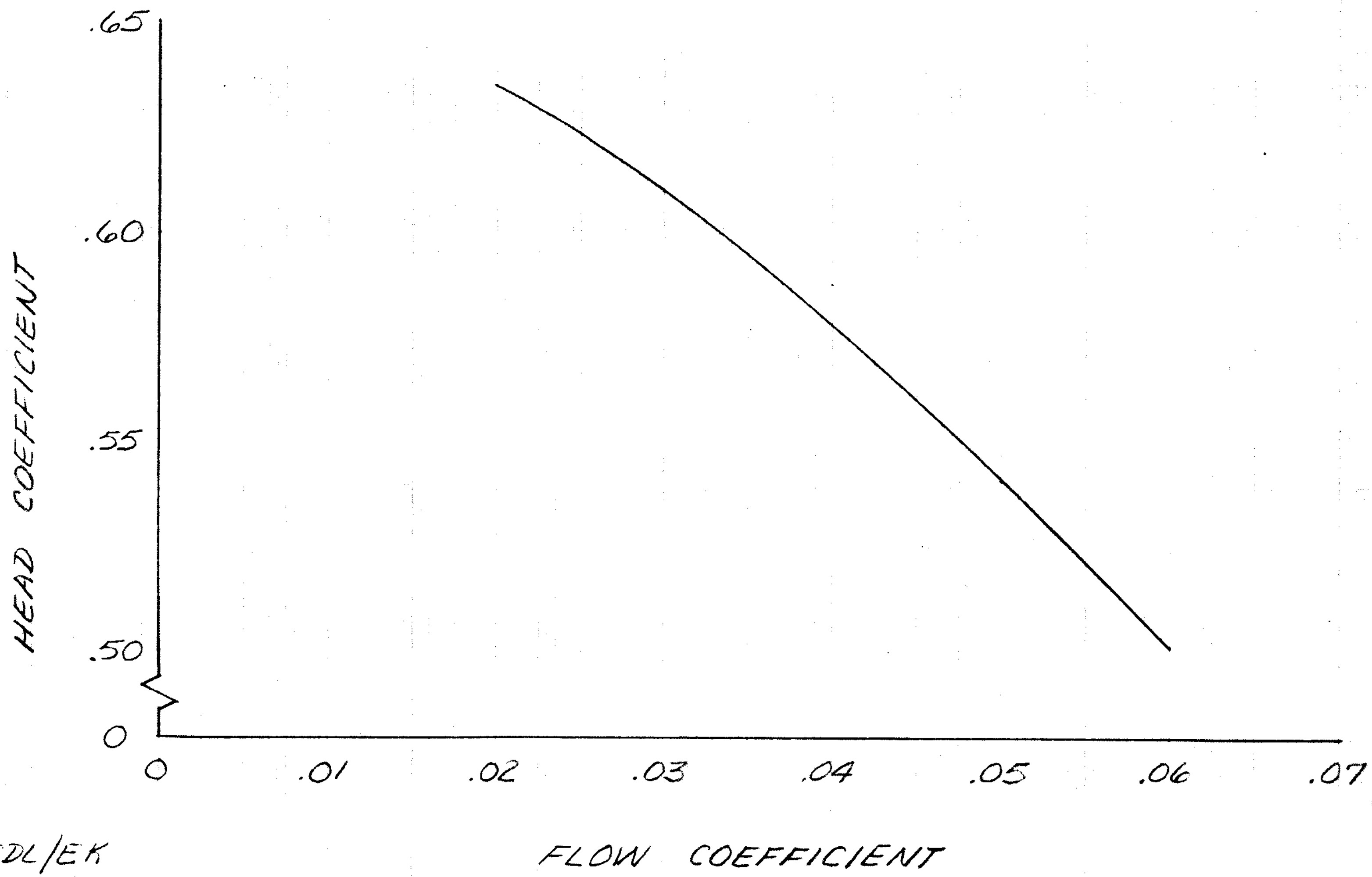
DF 97953
FIGURE IV-4

Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER

FUEL PUMP FIRST STAGE PERFORMANCE CHARACTERISTICS
DERIVATIVE IIB ENGINE



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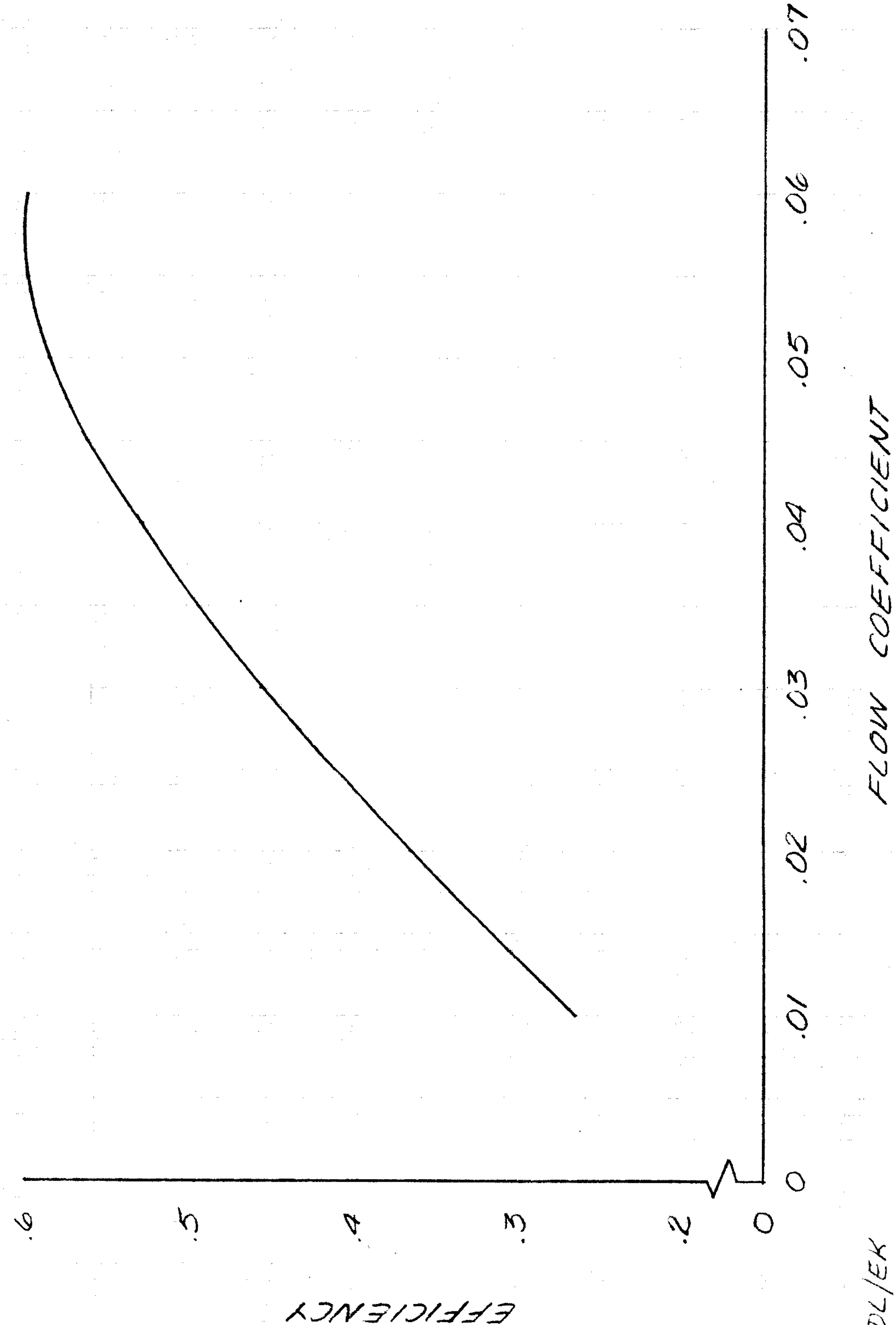
DF 97954
FIGURE IV-5

DF97955
FIGURE IV-6

Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER

FUEL PUMP SECOND STAGE PERFORMANCE CHARACTERISTICS
DERIVATIVE IIA & IIB ENGINES



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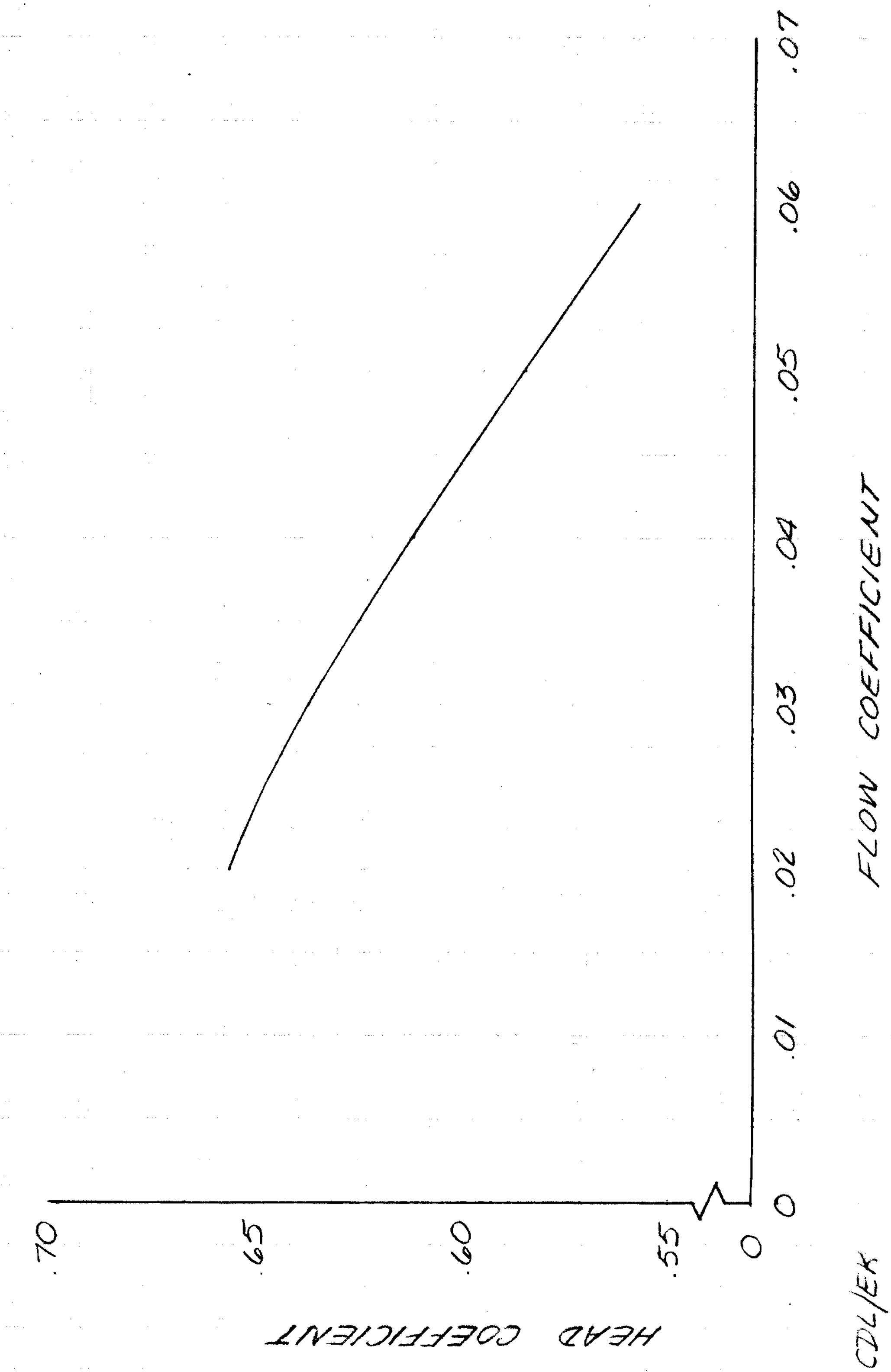
DF97956
FIGURE IV-7

Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER

FUEL PUMP SECOND STAGE PERFORMANCE CHARACTERISTICS
DERIVATIVE IIA & IIB ENGINES



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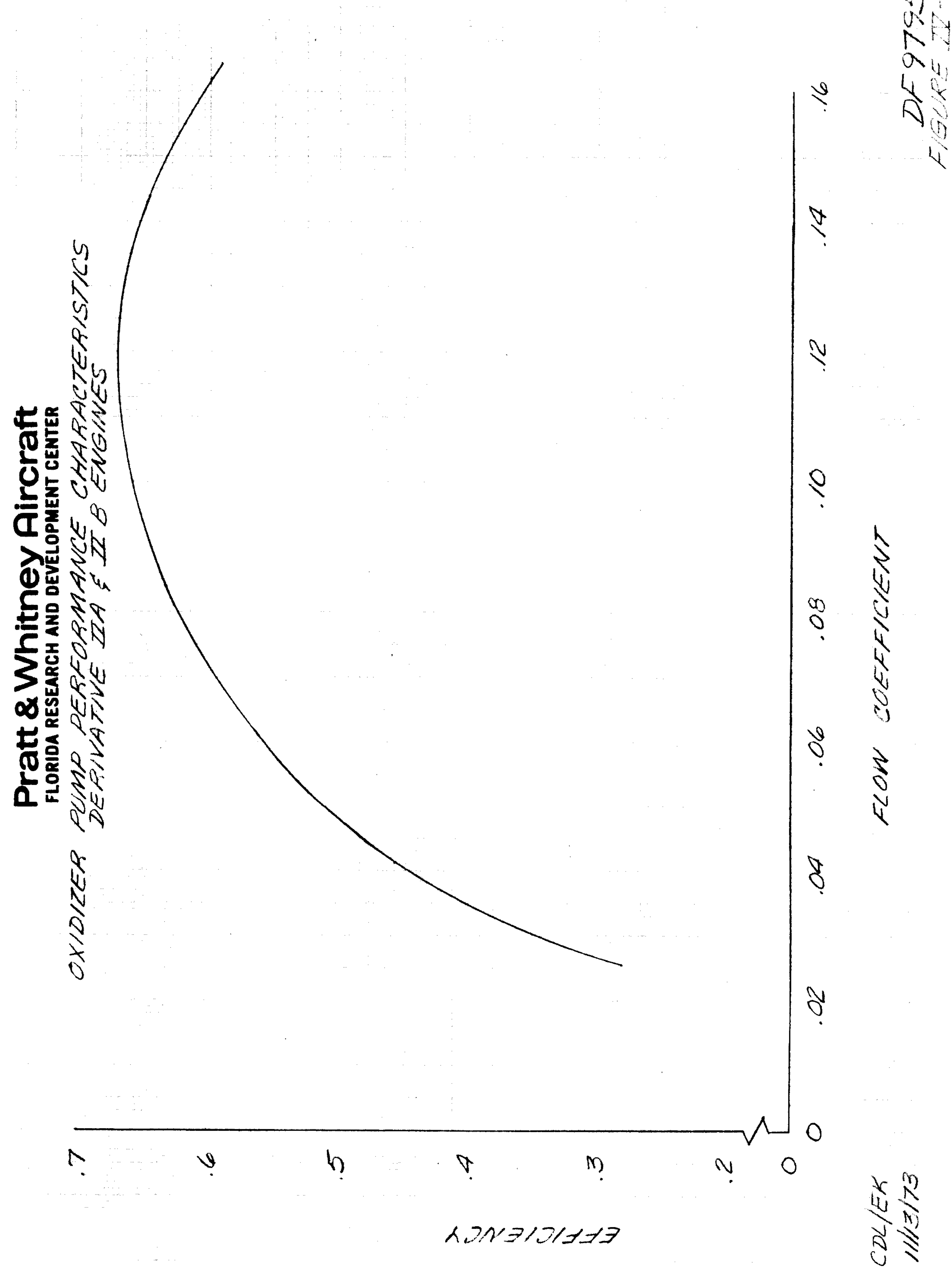
Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER
OXIDIZER PUMP PERFORMANCE CHARACTERISTICS
DERIVATIVE IIA & IIB ENGINES
EFFICIENCY
.7
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.06
.08
.10
.12
.14
.16
FLOW COEFFICIENT
DF 97957
FIGURE IV-8
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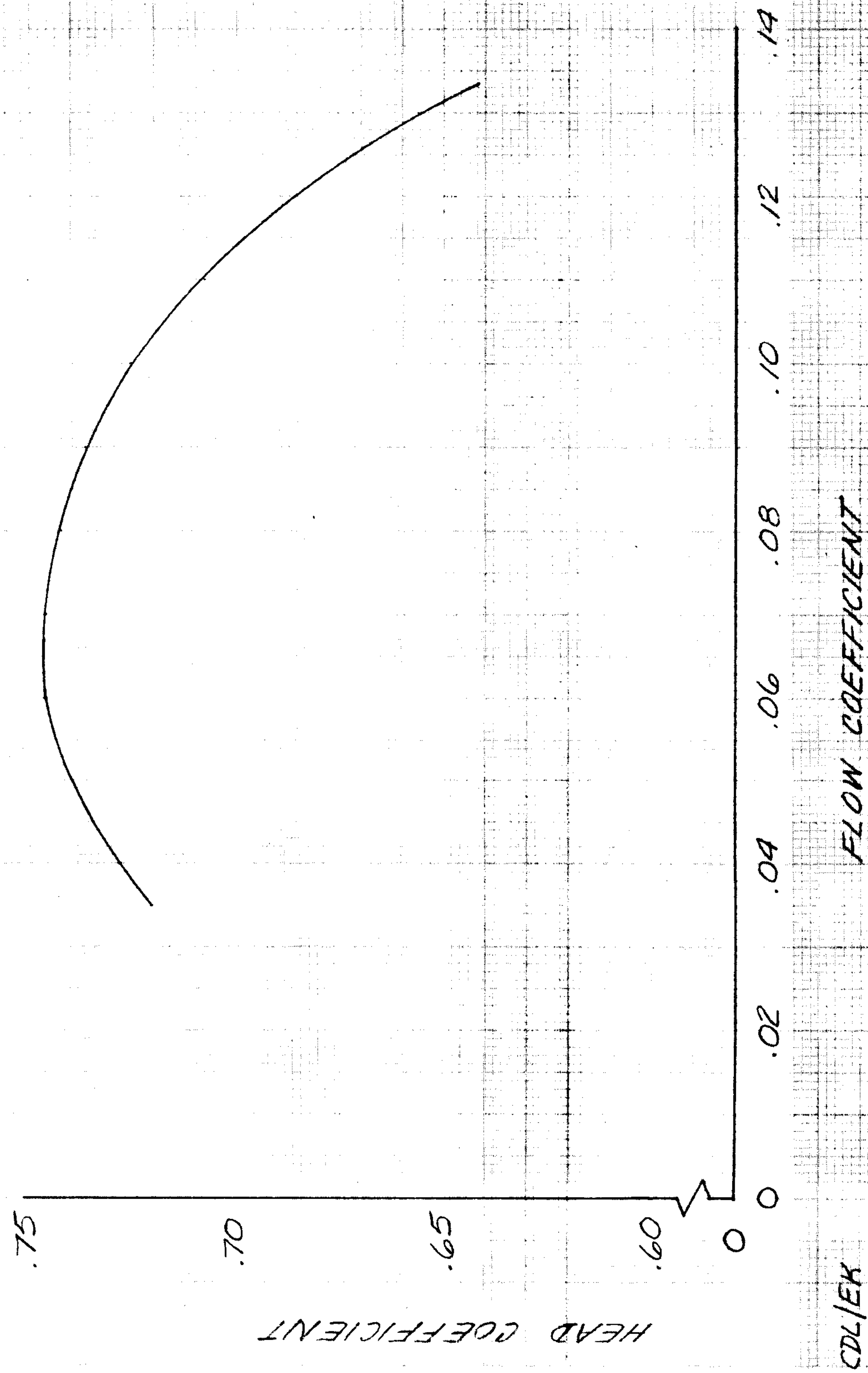
Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER

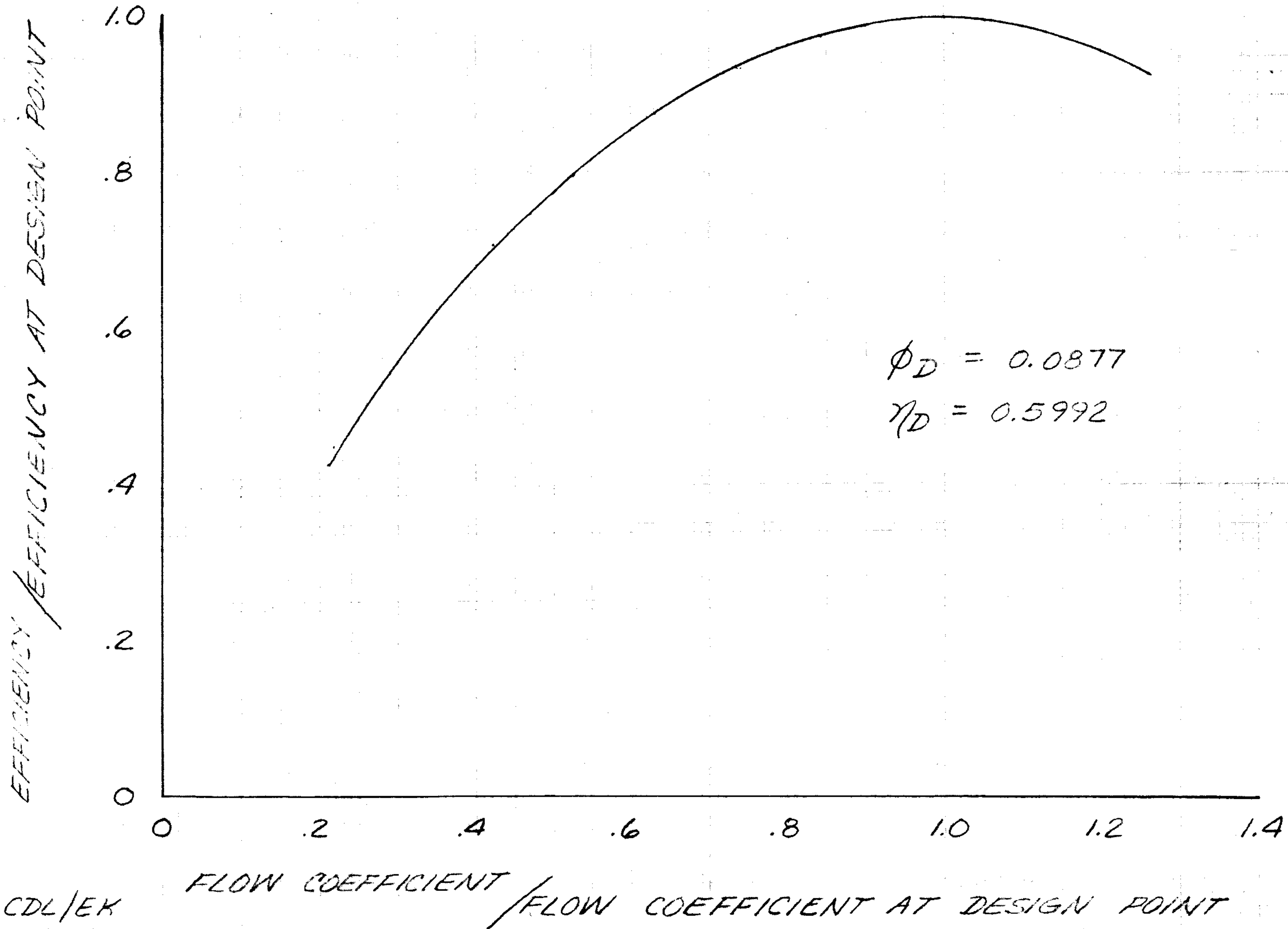
OXIDIZER PUMP PERFORMANCE CHARACTERISTICS
DERIVATIVE IIA & IIB ENGINES



DF 97958
FIGURE IV-9

Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER

FUEL PUMP FIRST AND SECOND STAGE PERFORMANCE CHARACTERISTICS
CATEGORY IV ENGINE



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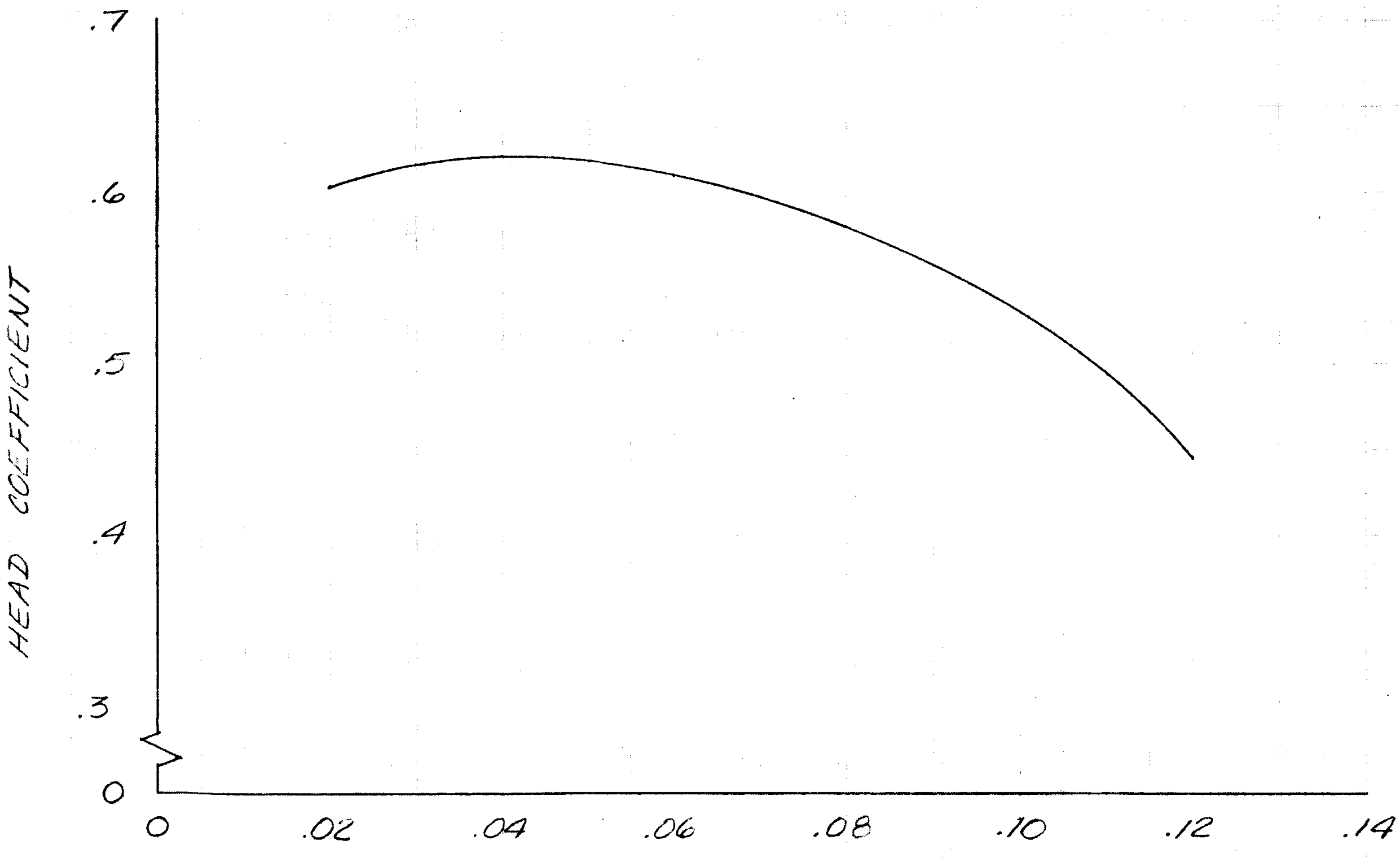
DF 97959
FIGURE IV-10

Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER

FUEL PUMP FIRST AND SECOND STAGE PERFORMANCE CHARACTERISTICS
CATEGORY IV ENGINE



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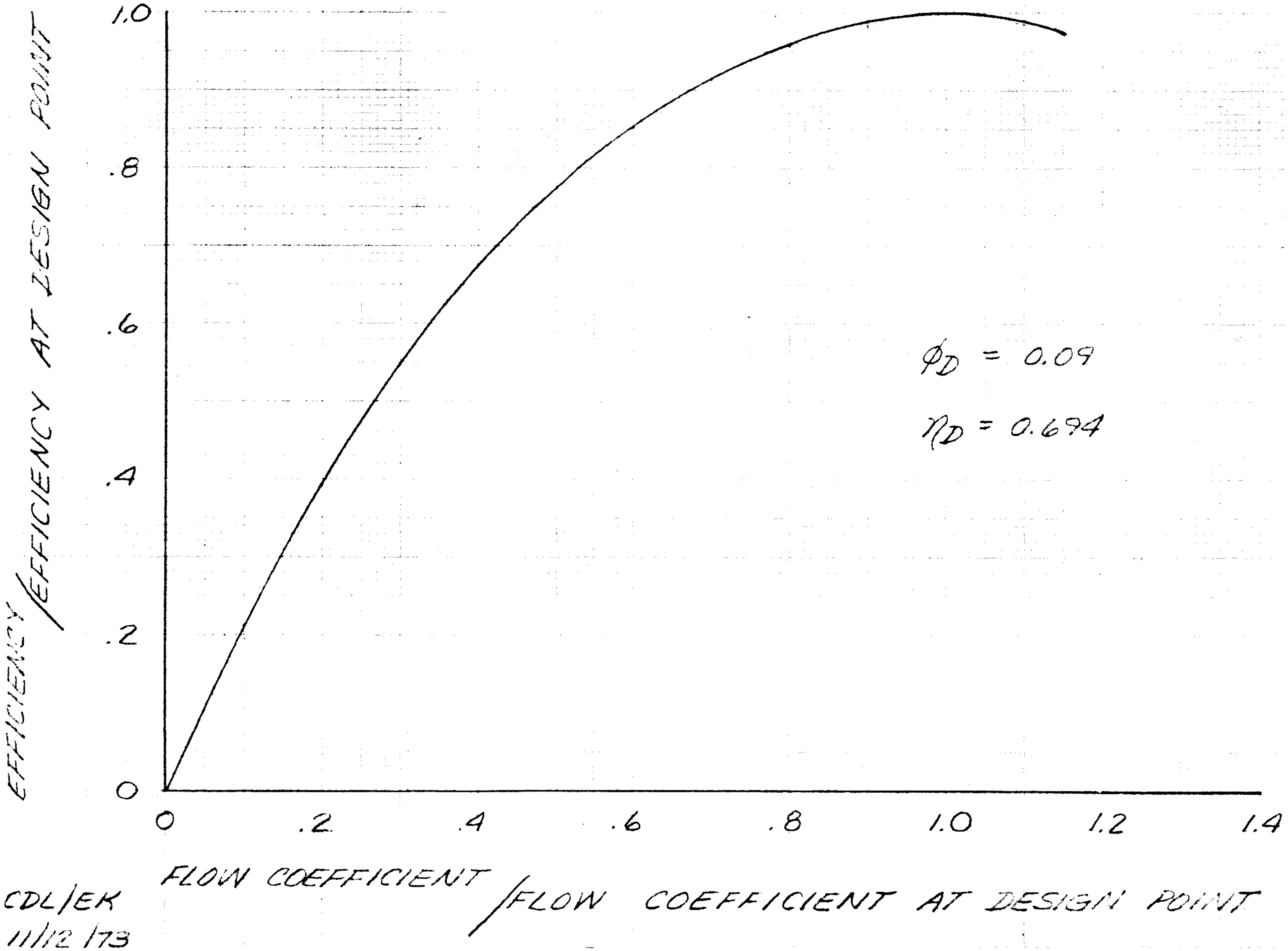
DF 97960
FIGURE IV-11

Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER

OXIDIZER PUMP PERFORMANCE CHARACTERISTICS
CATEGORY IV ENGINE



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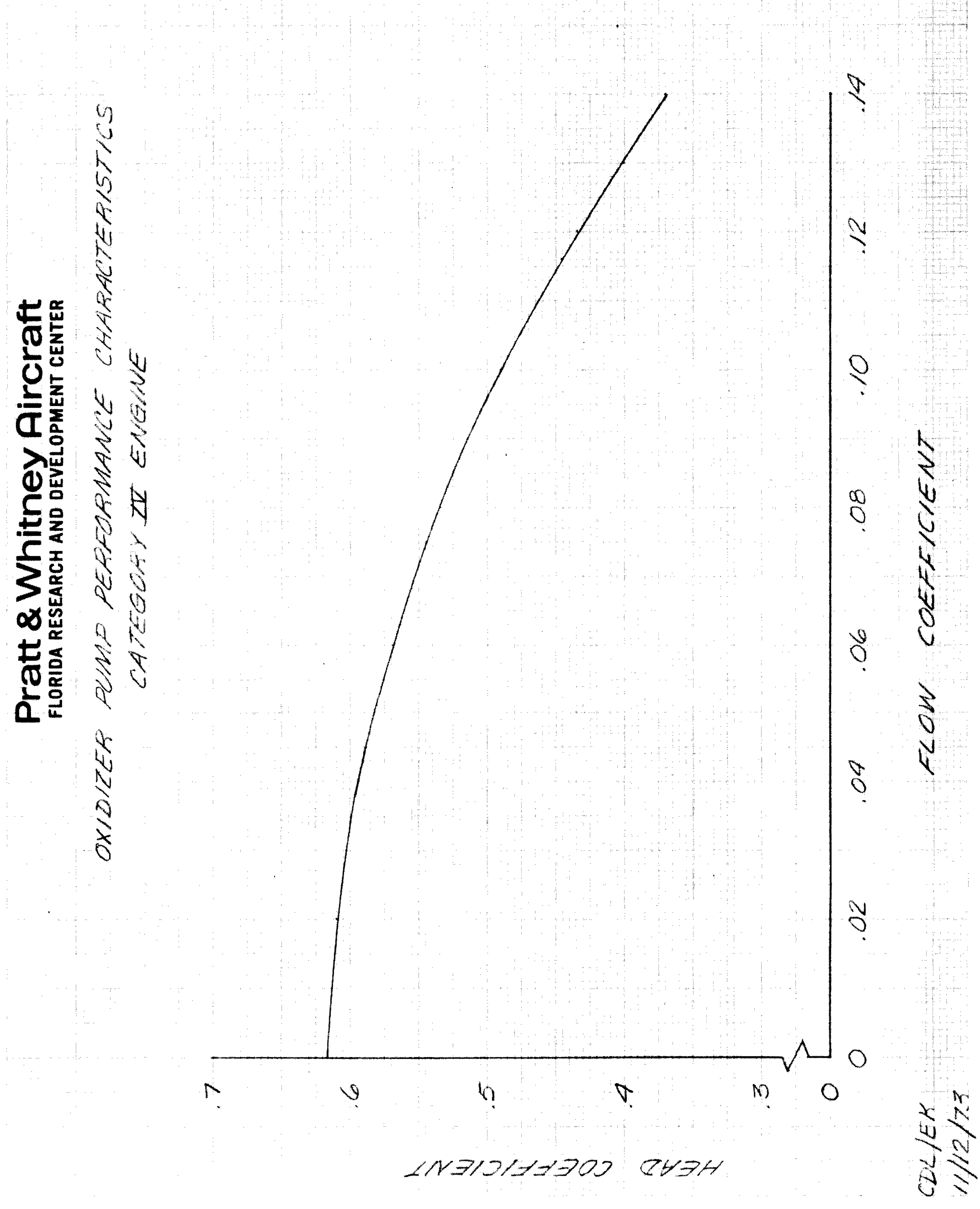
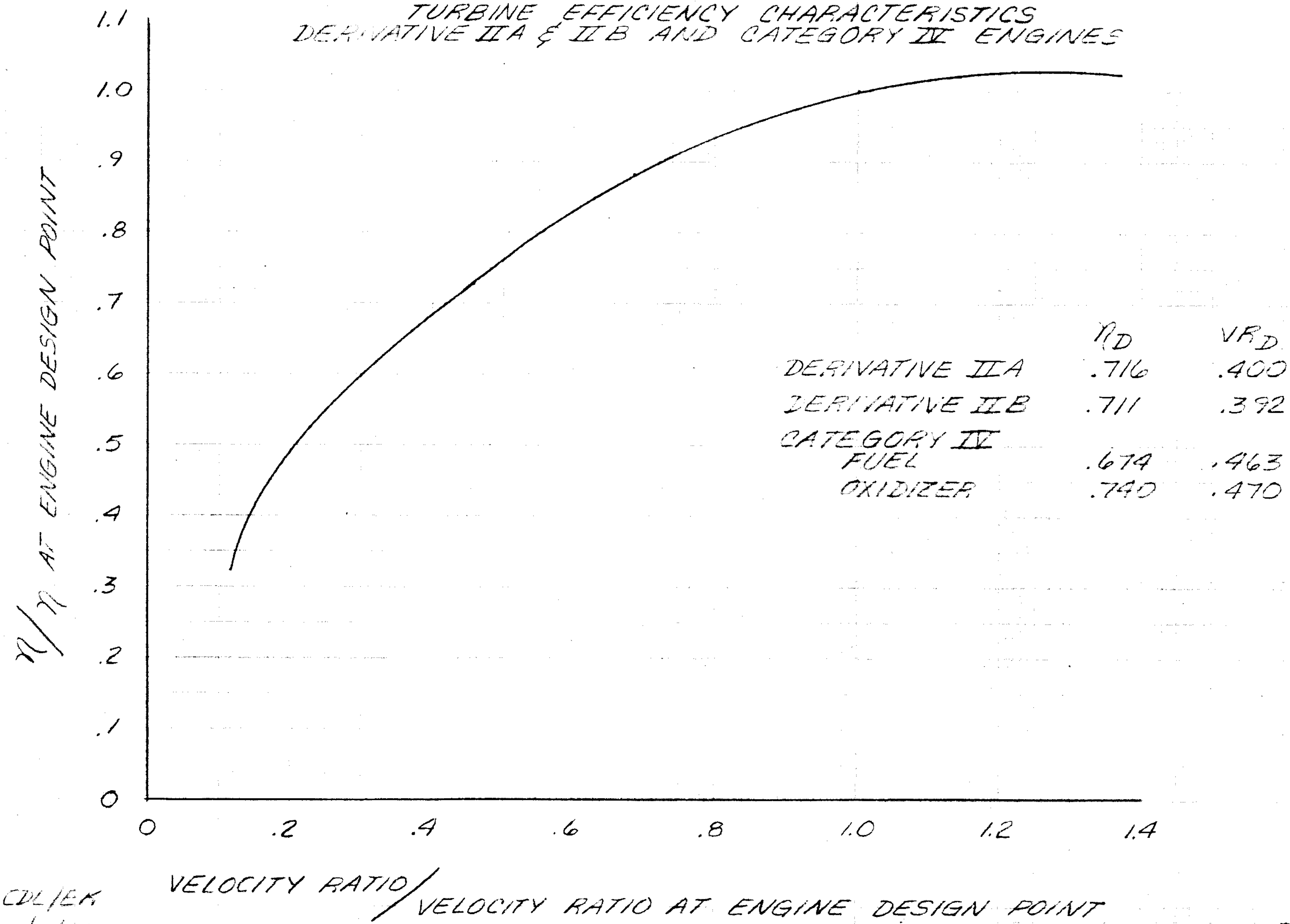
DF 97961
FIGURE IV-12

DF 97962
FIGURE IV-13



Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER

TURBINE EFFICIENCY CHARACTERISTICS
DERIVATIVE IIA & IIB AND CATEGORY IV ENGINES



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11/8/73

DF 97681
FIGURE IV-14

MODIFIED RL10 OFF-DESIGN DECK

DERIVATIVE II A BASE CASE RM=6.0 8-21-73

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.0	PRESSURE	16.0
TEMP	36.9	TEMP	163.8
NPSP	0.0	NPSP	0.0
FLOW	4.67	FLOW	28.03

LOX LSI

SPEED	3022.
FLOW	28.028
POWER	2.74
EFF	0.6475
DISCH P	33.25
DISCH T	163.9
RHO IN	70.893

FUEL TURBINE

FLOW	3.958
POWER	541.11
EFF	0.7159
INLET P	653.48
INLET T	474.3
DIS P(S)	487.29
DELH ACT	96.7
M. VEL R	0.400
ACD	1.072
TDIS MIX	451.07
HP TRANS	81.2
P/P	1.341

FUEL PUMP

SPEED	28571.
FLOW	4.671
INLET GPM	461.9

* 1ST STAGE *

POWER	207.82
EFF	0.5172
INLET P	16.00
DISCH P	405.11
DISCH T	44.873
RHO IN	4.398
RHO OUT	4.315

* 2ND STAGE *

POWER	252.11
EFF	0.4902
INLET P	405.11
DISCH P	821.36
DISCH T	55.7
RHO OUT	4.145

LOX PUMP

SPEED	11428.
FLOW	28.028
POWER	81.17
EFF	0.6345
INLET P	33.25
INLET T	163.9
DISCH P	530.80
DISCH T	166.9
RHO IN	70.893
RHO OUT	70.893
INLET GPM	177.5

FUEL INJECTOR

DELTA P	68.72
INLET P	468.64
INLET T	451.1
ACD	1.982
MV	51.249

LOX INJECTOR

DELTA P	46.71
INLET P	446.62
INLET T	167.2
ACD	0.730
RHO	70.719
MV	15.225

MIXTURE RATIO	6.000
THRUST	14998.
IMPULSE	458.65
CHAMBER PRESSURE	399.91

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	4.41	WLEAK	0.265	DELTA P	84.17	ACD	0.1053
INLET P	814.46	WT/P-FUEL	0.0	ACD	0.5428	WTBY/WF	9.185
INLET T	55.7	WT/P-LOX	0.0	K FACTOR	7.5961	WTBY	0.405
DELTA PJ	154.382	TOXP	0.0			P/P	1.393
DELTA TJ	418.538	POXP	0.0				
		PFP	468.637				
		TFP	451.067				

SYSTEM PRESSURE LOSSES	
OB/P DIS LINE	0.0
FB/P DIS LINE	0.0
PUMP INTR STG	0.0
PUMP DIS LINE	2.342
GOX HEAT EXR	0.600
JAC IN LINE	4.558
JAC DIS LINE	0.0
FUEL TURB IN	6.601
INJ IN LINE	13.998

CHAMBER	
PC (INJ FACE)	399.915
IMPULSE (CHAMBER)	458.883
IMPULSE (DELIVERED)	458.649
MIXTURE RATIO(INLET)	6.000
MIXTURE RATIO(CHAMBER)	6.361
CS	0.967
ETA C*	0.994
AREA RATIO	262.800

MODIFIED RL10 OFF-DESIGN DECK

DERIVATIVE II A BASE CASE RM=5.5 8-21-73

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.0	PRESSURE	16.0
TEMP	36.9	TEMP	163.8
NPSP	0.0	NPSP	0.0
FLOW	4.93	FLOW	27.13

LOX LSI

SPEED	3061.
FLOW	27.134
POWER	2.93
EFF	0.6372
DISCH P	34.70
DISCH T	163.9
RHO IN	70.893

FUEL TURBINE

FLOW	4.233
POWER	566.66
EFF	0.7212
INLET P	666.89
INLET T	439.5
DIS P(S)	490.30
DELP ACT	94.7
M. VEL R	0.411
ACD	1.070
TDIS MIX	416.97
HP TRANS	81.9
P/P	1.360

FUEL PUMP

SPEED	28937.
FLOW	4.933
INLET GPM	488.6

* 1ST STAGE *

POWER	218.89
EFF	0.5270
INLET P	16.00
DISCH P	411.68
DISCH T	44.767
RHO IN	4.398
RHO OUT	4.324

* 2ND STAGE *

POWER	265.92
EFF	0.5017
INLET P	411.68
DISCH P	839.82
DISCH T	55.5
RHO OUT	4.165

LOX PUMP

SPEED	11575.
FLOW	27.134
POWER	81.85
EFF	0.6265
INLET P	34.70
INLET T	163.9
DISCH P	546.45
DISCH T	167.1
RHO IN	70.892
RHO OUT	70.892
INLET GPM	171.8

FUEL INJECTOR

DELTA P	71.06
INLET P	471.21
INLET T	417.0
ACD	1.986
MV	52.834

LOX INJECTOR

DELTA P	43.80
INLET P	443.95
INLET T	167.5
ACD	0.730
RHO	70.676
MV	14.278

MIXTURE RATIO	5.500
THRUST	14823.
IMPULSE	462.25
CHAMBER PRESSURE	400.15

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	4.67	WLEAK	0.265	DELTA P	102.49	ACD	0.0945
INLET P	832.11	WT/P-FUEL	0.0	ACD	0.4762	WTBY/WF	8.321
INLET T	55.5	WT/P-LOX	0.0	K FACTOR	9.8692	WTBY	0.388
DELTA PJ	158.480	TOXP	0.0			P/P	1.414
DELTA TJ	383.995	POXP	0.0				
		PFP	471.209				
		TFP	416.969				

SYSTEM PRESSURE LOSSES	
OB/P DIS LINE	0.0
FB/P DIS LINE	0.0
PUMP INTR STG	0.0
PUMP DIS LINE	2.617
GOX HEAT EXR	0.600
JAC IN LINE	5.092
JAC DIS LINE	0.0
FUEL TURB IN	6.736
INJ IN LINE	14.435

CHAMBER	
PC (INJ FACE)	400.149
IMPULSE (CHAMBER)	462.520
IMPULSE (DELIVERED)	462.251
MIXTURE RATIO(INLET)	5.500
MIXTURE RATIO(CHAMBER)	5.812
CS	0.967
FTA C*	0.994
AREA RATIO	262.800

MODIFIED RL10 OFF-DESIGN DECK

DERIVATIVE II A   BASE CASE   RM=6.5   8-21-73

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.0	PRESSURE	16.0
TEMP	36.9	TEMP	163.8
NPSP	0.0	NPSP	0.0
FLOW	4.46	FLOW	29.02

LOX LSI

SPEED	2991.
FLOW	29.016
POWER	2.65
EFF	0.6405
DISCH P	31.91
DISCH T	163.9
RHO IN	70.893

FUEL TURBINE

FLOW	3.761
POWER	522.20
EFF	0.7099
INLET P	643.40
INLET T	503.4
DIS P(S)	484.62
DELH ACT	98.2
M. VEL R	0.391
ACD	1.075
TDIS MIX	479.59
HP TRANS	81.1
P/P	1.328

FUEL PUMP

SPEED	28284.
FLOW	4.464
INLET GPM	440.7

* 1ST STAGE *

POWER	199.81
EFF	0.5076
INLET P	16.00
DISCH P	399.83
DISCH T	45.005
RHO IN	4.398
RHO OUT	4.307

* 2ND STAGE *

POWER	241.28
EFF	0.4809
INLET P	399.83
DISCH P	806.67
DISCH T	55.9
RHO OUT	4.127

LOX PUMP

SPEED	11314.
FLOW	29.016
POWER	81.12
EFF	0.6417
INLET P	31.91
INLET T	163.9
DISCH P	517.66
DISCH T	166.8
RHO IN	70.893
RHO OUT	70.893
INLET GPM	183.7

FUEL INJECTOR

DELTA P	66.53
INLET P	466.43
INLET T	479.6
ACD	1.979
MV	49.766

LOX INJECTOR

DELTA P	50.04
INLET P	449.93
INLET T	167.0
ACD	0.730
RHO	70.755
MV	16.309

MIXTURE RATIO	6.500
THRUST	15128.
IMPULSE	451.85
CHAMBER PRESSURE	399.90

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	4.20	WLEAK	0.265	DELTA P	67.73	ACD	0.1087
INLET P	800.38	WT/P-FUEL	0.0	ACD	0.6265	WTBY/WF	9.443
INLET T	55.9	WT/P-LOX	0.0	K FACTOR	5.7028	WTBY	0.397
DELTA PJ	150.481	TOXP	0.0			P/P	1.378
DELTA TJ	447.439	POXP	0.0				
		PFP	466.427				
		TFP	479.588				

SYSTEM PRESSURE LOSSES	
OB/P DIS LINE	0.0
FB/P DIS LINE	0.0
PUMP INTR STG	0.0
PUMP DIS LINE	2.136
GOX HEAT EXR	0.600
JAC IN LINE	4.157
JAC DIS LINE	0.0
FUEL TURB IN	6.499
INJ IN LINE	13.590

CHAMBER	
PC (INJ FACE)	399.898
IMPULSE (CHAMBER)	452.027
IMPULSE (DELIVERED)	451.853
MIXTURE RATIO(INLET)	6.500
MIXTURE RATIO(CHAMBER)	6.910
CS	0.966
ETA C*	0.991
AREA RATIO	262.800

MODIFIED RL10 OFF-DESIGN DECK

DERIVATIVE II A   PUMPED IDLE   8-21-73

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.0	PRESSURE	16.0
TEMP	36.9	TEMP	163.8
NPSP	0.0	NPSP	0.0
FLOW	1.22	FLOW	7.35

LOX LSI

SPEED	1435.
FLOW	7.347
POWER	0.39
EFF	0.4282
DISCH P	22.21
DISCH T	163.9
RHO IN	70.893

FUEL TURBINE

FLOW	0.707
POWER	53.47
EFF	0.5651
INLET P	152.46
INLET T	621.8
DIS P(S)	130.00
DELH ACT	53.5
M. VEL R	0.227
ACD	1.137
TDIS MIX	612.26
HP TRANS	7.5
P/P	1.173

FUEL PUMP

SPEED	13564.
FLOW	1.224
INLET GPM	118.9

* 1ST STAGE *

POWER	20.96
EFF	0.3172
INLET P	16.00
DISCH P	109.18
DISCH T	40.472
RHO IN	4.398
RHO OUT	4.309

* 2ND STAGE *

POWER	25.04
EFF	0.2900
INLET P	109.18
DISCH P	205.01
DISCH T	44.9
RHO OUT	4.172

LOX PUMP

SPEED	5425.
FLOW	7.347
POWER	7.47
EFF	0.4037
INLET P	22.21
INLET T	163.9
DISCH P	133.11
DISCH T	165.2
RHO IN	70.888
RHO OUT	70.771
INLET GPM	46.5

FUEL INJECTOR

DELTA P	22.49
INLET P	124.82
INLET T	612.3
ACD	2.009
MV	16.293

LOX INJECTOR

DELTA P	3.21
INLET P	105.54
INLET T	165.3
ACD	0.730
RHO	70.771
MV	1.045

MIXTURE RATIO	6.000
THRUST	3750.
IMPULSE	437.50
CHAMBER PRESSURE	102.34

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
***************		***************		***************		***************	
FLOW	1.12	WLEAK	0.108	DELTA P	27.56	ACD	0.6169
INLET P	204.57	WT/P-FUEL	0.0	ACD	0.2489	WTBY/WF	36.658
INLET T	44.9	WT/P-LOX	0.0	K FACTOR	36.1394	WTBY	0.409
DELTA PJ	50.570	TOXP	0.0			P/P	1.203
DELTA TJ	576.901	POXP	0.0				
		PFP	124.822				
		TFP	612.262				

SYSTEM PRESSURE LOSSES	
************************	
OB/P DIS LINE	0.0
FB/P DIS LINE	0.0
PUMP INTR STG	0.0
PUMP DIS LINE	0.149
GOX HEAT EXP	0.000
JAC IN LINE	0.291
JAC DIS LINE	0.0
FUEL TURB IN	1.540
INJ IN LINE	4.554

CHAMBER	
*****************************	
PC (INJ FACE)	102.336
IMPULSE (CHAMBER)	438.113
IMPULSE (DELIVERED)	437.504
MIXTURE RATIO(INLET)	6.000
MIXTURE RATIO(CHAMBER)	6.578
CS	0.957
ETA C*	0.994
AREA RATIO	262.800

PRATT & WHITNEY AIRCRAFT

Florida Research and Development Center

Derivative IIA Engine

TANK HEAD IDLE

INLET CONDITIONS

Fuel

Pressure = 16.0 psia
Temperature = 36.9 °R
Saturated Liquid

Oxidizer

Pressure = 16.0 psia
Temperature = 163.8 °R
Saturated Liquid

Fuel Side

Flow = .08 lb/sec

Jacket Inlet Temperature =	36.8 °R
Jacket Inlet Pressure =	15.9 PSIA
Jacket Discharge Temperature =	582. °R
Jacket Discharge Pressure =	10.3 PSIA
Injector Inlet Temperature =	426. °R
Injector Inlet Pressure =	6.8 PSIA
Dump Nozzle Coolant Flow =	0.006 LB/SEC

Oxidizer Side

Flow = 0.32 lb/sec

Main Pump Discharge Temperature =	163.8 °R
Main Pump Discharge Pressure =	15.9 PSIA
Injector Inlet Temperature =	385. °R
Injector Inlet Pressure =	14.5 PSIA
Injector Pressure Loss =	9.3 °R

Chamber Pressure =	5.2 PSIA
Thrust =	157. LB_f.
Mixture Ratio =	4.0
Impulse =	387. sec
Chamber Mixture Ratio =	4.3

MODIFIED RL10 OFF-DESIGN DECK

DERIVATIVE IIB O/F=6.0 8-21-73

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.43	PRESSURE	19.71
TEMP	36.9	TEMP	163.8
NPSP	.43	NPSP	3.71
FLOW	4.67	FLOW	28.03

FUEL TURBINE

FLOW	3.948
POWER	529.61
EFF	0.7105
INLET P	651.25
INLET T	473.7
DIS P(S)	487.13
DELH ACT	94.9
M. VEL R	0.392
ACD	1.076
TDIS MIX	451.02
HP TRANS	76.6
P/P	1.337

FUEL PUMP (MAIN)

SPEED	27852.
FLOW	4.671
INLET GPM	461.9

* 1ST STAGE *

POWER	217.03
EFF	0.5209
INLET P	16.43
DISCH P	425.15
DISCH T	45.214
RHO IN	4.398
RHO OUT	4.314

* 2ND STAGE *

POWER	235.97
EFF	0.4949
INLET P	425.15
DISCH P	819.27
DISCH T	55.4
RHO OUT	4.156

LOX PUMP (MAIN)

SPEED	11141.
FLOW	28.028
POWER	76.62
EFF	0.6375
INLET P	19.71
INLET T	163.8
DISCH P	487.98
DISCH T	166.6
RHO IN	70.893
RHO OUT	70.893
INLET GPM	177.5

FUEL INJECTOR

DELTA P	68.61
INLET P	468.70
INLET T	451.0
ACD	1.982
MV	51.241

LOX INJECTOR

DELTA P	46.66
INLET P	446.75
INLET T	166.8
ACD	0.730
RHO	70.795
MV	15.208

MIXTURE RATIO	6.000
THRUST	14997.
IMPULSE	458.65
CHAMBER PRESSURE	400.09

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	4.41	WLEAK	0.265	DELTA P	41.24	ACD	0.1083
INLET P	812.39	WT/P-FUEL	0.0	ACD	0.7755	WTBY/WF	9.401
INLET T	55.4	WT/P-LOX	0.0	K FACTOR	3.7217	WTBY	0.414
DELTA PJ	154.557	TOXP	0.0			P/P	1.388
DELTA TJ	418.333	POXP	0.0				
		PFP	468.699				
		TFP	451.019				

SYSTEM PRESSURE LOSSES	
OB/P DIS LINE	0.0
FB/P DIS LINE	0.0
PUMP INTR STG	0.0
PUMP DIS LINE	2.336
GOX HEAT EXR	0.0
JAC IN LINE	4.545
JAC DIS LINE	0.0
FUEL TURB IN	6.578
INJ IN LINE	13.995

CHAMBER	
PC (INJ FACE)	400.088
IMPULSE (CHAMBER)	458.883
IMPULSE (DELIVERED)	458.649
MIXTURE RATIO(INLET)	6.000
MIXTURE RATIO(CHAMBER)	6.361
CS	0.967
ETA C*	0.994
AREA RATIO	262.800

MODIFIED RL10 OFF-DESIGN DECK

DERIVATIVE IIB   O/F=5.5   8-21-73

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.43	PRESSURE	19.71
TEMP	36.9	TEMP	163.8
NPSP	.43	NPSP	3.71
FLOW	4.93	FLOW	27.13

FUEL TURBINE

FLOW	4.218
POWER	553.71
EFF	0.7172
INLET P	663.97
INLET T	438.7
DIS P(S)	489.99
DELH ACT	92.8
M. VEL R	0.403
ACD	1.073
TDIS MIX	416.64
HP TRANS	76.9
P/P	1.355

FUEL PUMP (MAIN)

SPEED	28155.
FLOW	4.933
INLET GPM	488.6
* 1ST STAGE *	
POWER	229.34
EFF	0.5299
INLET P	16.43
DISCH P	432.65
DISCH T	45.138
RHO IN	4.398
RHO OUT	4.322
* 2ND STAGE *	
POWER	247.50
EFF	0.5071
INLET P	432.65
DISCH P	837.00
DISCH T	55.2
RHO OUT	4.180

LOX PUMP (MAIN)

SPEED	11262.
FLOW	27.132
POWER	76.88
EFF	0.6305
INLET P	19.71
INLET T	163.8
DISCH P	499.81
DISCH T	166.8
RHO IN	70.893
RHO OUT	70.893
INLET GPM	171.8

FUEL INJECTOR

DELTA P	70.99
INLET P	471.12
INLET T	416.6
ACD	1.986
MV	52.800

LOX INJECTOR

DELTA P	43.74
INLET P	443.88
INLET T	167.0
ACD	0.730
RHO	70.761
MV	14.258

MIXTURE RATIO	5.500
THRUST	14821.
IMPULSE	462.24
CHAMBER PRESSURE	400.13

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	4.67	WLEAK	0.265	DELTA P	55.94	ACD	0.0986
INLET P	829.33	WT/P-FUEL	0.0	ACD	0.6446	WTBY/WF	8.635
INLET T	55.2	WT/P-LOX	0.0	K FACTOR	5.3871	WTBY	0.403
DELTA PJ	158.646	TOXP	0.0			P/P	1.408
DELTA TJ	383.511	POXP	0.0				
		PFP	471.121				
		TFP	416.642				

SYSTEM PRESSURE LOSSES	
OB/P DIS LINE	0.0
FB/P DIS LINE	0.0
PUMP INTR STG	0.0
PUMP DIS LINE	2.607
GOX HEAT EXR	0.0
JAC IN LINE	5.072
JAC DIS LINE	0.0
FUEL TURB IN	6.707
INJ IN LINE	14.424

CHAMBER	
PC (INJ FACE)	400.133
IMPULSE (CHAMBER)	462.506
IMPULSE (DELIVERED)	462.237
MIXTURE RATIO(INLET)	5.500
MIXTURE RATIO(CHAMBER)	5.812
CS	0.967
ETA C*	0.994
AREA RATIO	262.800

MODIFIED RL10 OFF-DESIGN DECK

DERIVATIVE IIB O/F=6.5 8-21-73

INLETT CONDITIONS

FUEL		LOX	
PRESSURE	16.43	PRESSURE	19.71
TEMP	36.9	TEMP	163.8
NPSP	.43	NPSP	3.71
FLOW	4.46	FLOW	29.02

FUEL TURBINE

FLOW	3.750
POWER	511.25
EFF	0.7048
INLET P	641.24
INLET T	503.2
DIS P(S)	484.48
DELH ACT	96.4
M. VEL R	0.384
ACD	1.079
TDIS MIX	479.92
HP TRANS	76.8
P/P	1.324

FUEL PUMP (MAIN)

SPEED	27600.
FLOW	4.464
INLET GPM	440.7
* 1ST STAGE *	
POWER	207.97
EFF	0.5117
INLET P	16.43
DISCH P	418.64
DISCH T	45.321
RHO IN	4.398
RHO OUT	4.305
* 2ND STAGE *	
POWER	226.51
EFF	0.4853
INLET P	418.64
DISCH P	804.75
DISCH T	55.6
RHO OUT	4.139

LOX PUMP (MAIN)

SPEED	11040.
FLOW	29.017
POWER	76.76
EFF	0.6441
INLET P	19.71
INLET T	163.8
DISCH P	477.45
DISCH T	166.5
RHO IN	70.893
RHO OUT	70.893
INLET GPM	183.7

FUEL INJECTOR

DELTA P	66.34
INLET P	466.48
INLET T	479.9
ACD	1.979
MV	49.805

LOX INJECTOR

DELTA P	49.94
INLET P	450.09
INLET T	166.6
ACD	0.730
RHO	70.893
MV	16.278

MIXTURE RATIO	6.500
THRUST	15129.
IMPULSE	451.86
CHAMBER PRESSURE	400.14

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	4.20	WLEAK	0.265	DELTA P	27.36	ACD	0.1122
INLET P	798.47	WT/P-FUEL	0.0	ACD	0.9857	WTBY/WF	9.693
INLET T	55.6	WT/P-LOX	0.0	K FACTOR	2.3037	WTBY	0.407
DELTA PJ	150.757	TOXP	0.0			P/P	1.373
DELTA TJ	447.606	POXP	0.0				
		PFP	466.483				
		TFP	479.917				

SYSTEM PRESSURE LOSSES	
OB/P DIS LINE	0.0
FB/P DIS LINE	0.0
PUMP INTR STG	0.0
PUMP DIS LINE	2.130
GOX HEAT EXR	0.0
JAC IN LINE	4.145
JAC DIS LINE	0.0
FUEL TURB IN	6.477
INJ IN LINE	13.598

CHAMBER	
PC (INJ FACE)	400.145
IMPULSE (CHAMBER)	452.037
IMPULSE (DELIVERED)	451.862
MIXTURE RATIO(INLET)	6.500
MIXTURE RATIO(CHAMBER)	6.910
CS	0.966
ETA C*	0.991
AREA RATIO	262.800

MODIFIED RL10 OFF-DESIGN DECK

DERIVATIVE IIB PUMPED IDLE 8-21-73

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.0	PRESSURE	16.0
TEMP	36.9	TEMP	163.8
NPSP	0.0	NPSP	0.0
FLOW	1.22	FLOW	7.35

FUEL TURBINE

FLOW	0.709
POWER	53.28
EFF	0.5612
INLET P	152.46
INLET T	621.7
DIS P(S)	129.94
DELH ACT	53.1
M. VEL R	0.223
ACD	1.139
TDIS MIX	612.21
HP TRANS	7.2
P/P	1.173

FUEL PUMP (MAIN)

SPEED	13361.
FLOW	1.224
INLET GPM	118.8

* 1ST STAGE *

POWER	21.81
EFF	0.3153
INLET P	16.0
DISCH P	111.99
DISCH T	40.501
RHO IN	4.405
RHO OUT	4.310

* 2ND STAGE *

POWER	24.24
EFF	0.2906
INLET P	111.99
DISCH P	205.00
DISCH T	44.8
RHO OUT	4.178

LOX PUMP (MAIN)

SPEED	5344.
FLOW	7.347
POWER	7.23
EFF	0.4052
INLET P	16.0
INLET T	163.8
DISCH P	123.82
DISCH T	165.0
RHO IN	70.893
RHO OUT	70.781
INLET GPM	46.5

FUEL INJECTOR

DELTA P	22.47
INLET P	124.80
INLET T	612.2
ACD	2.009
MV	16.295

LOX INJECTOR

DELTA P	3.21
INLET P	105.53
INLET T	165.1
ACD	0.730
RHO	70.781
MV	1.045

MIXTURE RATIO	6.000
THRUST	3750.
IMPULSE	437.50
CHAMBER PRESSURE	102.32

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	1.12	WLEAK	0.108	DELTA P	18.29	ACD	0.6141
INLET P	204.56	WT/P-FUEL	0.0	ACD	0.3055	WTBY/WF	36.504
INLET T	44.8	WT/P-LOX	0.0	K FACTOR	23.9815	WTBY	0.408
DELTA PJ	50.557	TOXP	0.0			P/P	1.204
DELTA TJ	576.935	POXP	0.0				
		PFP	124.798				
		TFP	612.215				

SYSTEM PRESSURE LOSSES	
OB/P DIS LINE	0.0
FB/P DIS LINE	0.0
PUMP INTR STG	0.0
PUMP DIS LINE	0.149
GOX HEAT EXR	0.0
JAC IN LINE	0.290
JAC DIS LINE	0.0
FUEL TURB IN	1.540
INJ IN LINE	4.554

CHAMBER	
PC (INJ FACE)	102.324
IMPULSE (CHAMBER)	438.108
IMPULSE (DELIVERED)	437.498
MIXTURE RATIO(INLET)	6.000
MIXTURE RATIO(CHAMBER)	6.578
CS	0.957
ETA C*	0.994
AREA RATIO	262.800

PRATT & WHITNEY AIRCRAFT

Florida Research and Development Center

Derivative IIB Engine

TANK HEAD IDLE

INLET CONDITIONS

Fuel

Pressure = 16.0 psia
Temperature = 36.9 °R
Saturated Liquid

Oxidizer

Pressure = 16.0 psia
Temperature = 163.8 °R
Saturated Liquid

Fuel Side

Flow = .08 lb/sec

Jacket Inlet Temperature =	36.8 °R
Jacket Inlet Pressure =	15.9 PSIA
Jacket Discharge Temperature =	582. °R
Jacket Discharge Pressure =	10.3 PSIA
Injector Inlet Temperature =	426. °R
Injector Inlet Pressure =	6.8 PSIA
Dump Nozzle Coolant Flow =	0.006 LB/SEC

Oxidizer Side

Flow = 0.32 lb/sec

Main Pump Discharge Temperature =	163.8°R
Main Pump Discharge Pressure =	15.9PSIA
Injector Inlet Temperature =	385. °R
Injector Inlet Pressure =	14.5 PSIA
Injector Pressure Loss =	9.3 °R

Chamber Pressure =	5.2 PSIA
Thrust =	157. LB_f.
Mixture Ratio =	4.0
Impulse =	387. sec
Chamber Mixture Ratio =	4.3

RL10 EXTENSION OFF-DESIGN DECK

CATEGORY IV BASE CASE DATE 8-21-73 RM=6.0

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.0	PRESSURE	16.0
TEMP	36.9	TEMP	163.8
NPSP	0.0	NPSP	0.0
FLOW	4.56	FLOW	27.37

FUEL LSI		LOX LSI		FUEL PUMP (MAIN)		LOX PUMP (MAIN)	
SPEED	30450.	SPEED	3002.	SPEED	75048.	SPEED	38862.
						FLOW	27.374
FLOW	4.56	FLOW	27.37	FLOW	4.562	POWER	184.40
POWER	6.0	POWER	6.1	INLET GPM	462.6	EFF	0.6938
EFF	0.7337	EFF	0.6482	NPSP	17.57	INLET P	54.60
DISCH P	32.57	DISCH P	54.92			INLET T	164.0
RHO IN	4.405	RHO IN	70.893	* 1ST STAGE *		DISCH P	1321.54
				POWER	468.73	DISCH T	170.7
				EFF	0.5984	RHO IN	70.968
FUEL TURBINE		**LOX TURBINE**		INLET P	32.45	RHO OUT	70.970
				DISCH P	1047.06	INLET GPM	173.1
FLOW	4.018	FLOW	4.018	DISCH T	54.543	NPSP	38.46
POWER	931.23	POWER	218.40	RHO IN	4.427		
EFF	0.6741	EFF	0.7400	RHO OUT	4.316		
INLET P	1824.87	INLET P	1135.49				
INLET T	580.4	INLET T	537.4	* 2ND STAGE *			
DIS P(S)	1193.31	DIS P(S)	1032.32	POWER	484.05		
DELH ACT	163.9	DELH ACT	38.4	EFF	0.5980		
M. VEL R	0.463	M. VEL R	0.470	INLET P	1036.66		
ACD	0.405	ACD	1.020	DISCH P	2048.31		
PCT HP	97.12	PCT HP	114.67	DISCH T	72.8		
HP TRANS	21.5	P/P	1.100	RHO OUT	4.245		
P/P	1.529						

FUEL INJECTOR		LOX INJECTOR	
DELTA P	86.39	DELTA P	151.34
INLET P	1001.76	INLET P	1066.71
INLET T	530.4	INLET T	171.7
ACD	1.283	ACD	0.396
MV	41.603	RHO	70.566
		MV	26.794

MIXTURE RATIO	6.000
THRUST	15008.
IMPULSE	469.93
CHAMBER PRESSURE	915.37

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	4.26	WLEAK	0.300	DELTA P	254.83	ACD	0.0230
INLET P	2042.00	WT/P-FUEL	0.0	ACD	0.3045	WTBY/WF	5.720
INLET T	72.8	WT/P-LOX	0.0	K FACTOR	24.1359	WTBY	0.244
DELTA PJ	199.294	TOXP	0.0			P/P	1.839
DELTA TJ	507.560	POXP	3.000				
		TFP	530.382				

SYSTEM PRESSURE LOSSES	
OB/P DIS LINE	0.315
FB/P DIS LINE	0.124
PUMP INTR STG	10.398
PUMP DIS LINE	2.140
JAC IN LINE	4.164
JAC DIS LINE	0.0
FUEL TURB IN	17.834
FUEL TURB DIS	35.269
FUEL INTR LINE	22.544
INJ IN LINE	0.0
OX TURB IN	30.558
OX TURB DIS	0.0
INJ IN LINE	

CHAMBER	
PC (INJ FACE)	915.370
IMPULSE (CHAMBER)	470.313
IMPULSE (DELIVERED)	469.935
MIXTURE RATIO(INLET)	6.000
MIXTURE RATIO(CHAMBER)	6.422
CS	0.965
ETA C*	0.994
AREA RATIO	401.000

RL10 EXTENSION OFF-DESIGN DECK

CATEGORY IV BASE CASE DATE 8-21-73 RM=5.5

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.0	PRESSURE	16.0
TEMP	36.9	TEMP	163.8
NPSP	0.0	NPSP	0.0
FLOW	4.82	FLOW	26.51

FUEL LSI		LOX LSI	
SPEED	31322.	SPEED	3088.
FLOW	4.82	FLOW	26.51
POWER	6.5	POWER	6.8
EFF	0.7316	EFF	0.6364
DISCH P	32.91	DISCH P	60.48
RHO IN	4.405	RHO IN	70.893

FUEL TURBINE		LOX TURBINE	
FLOW	4.395	FLOW	4.395
POWER	1016.29	POWER	247.48
EFF	0.6788	EFF	0.7413
INLET P	1907.03	INLET P	1150.69
INLET T	538.3	INLET T	496.0
DIS P(S)	1212.32	DIS P(S)	1034.53
DELH ACT	163.5	DELH ACT	39.8
M. VEL R	0.478	M. VEL R	0.476
ACD	0.405	ACD	1.019
PCT HP	95.67	PCT HP	123.08
HP TRANS	39.4	P/P	1.112
P/P	1.573		

FUEL PUMP (MAIN)	
SPEED	77196.
FLOW	4.820
INLET GPM	488.8
NPSP	17.88
* 1ST STAGE *	
POWER	518.47
EFF	0.5975
INLET P	32.77
DISCH P	1092.62
DISCH T	55.343
RHO IN	4.426
RHO OUT	4.312
* 2ND STAGE *	
POWER	537.24
EFF	0.5954
INLET P	1081.01
DISCH P	2134.87
DISCH T	74.6
RHO OUT	4.234

LOX PUMP (MAIN)	
SPEED	39974.
FLOW	26.510
POWER	194.24
EFF	0.6892
INLET P	60.18
INLET T	164.1
DISCH P	1427.41
DISCH T	171.4
RHO IN	70.890
RHO OUT	70.956
INLET GPM	167.9
NPSP	44.00

FUEL INJECTOR		LOX INJECTOR	
DELTA P	87.72	DELTA P	142.34
INLET P	1002.89	INLET P	1057.50
INLET T	487.1	INLET T	172.8
ACD	1.283	ACD	0.396
MV	42.990	RHO	70.370
		MV	25.200

MIXTURE RATIO	5.500
THRUST	14794.
IMPULSE	472.20
CHAMBER PRESSURE	915.17

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	4.52	WLEAK	0.300	DELTA P	369.91	ACD	0.0108
INLET P	2127.76	WT/P-FUEL	0.0	ACD	0.2448	WTBY/WF	2.764
INLET T	74.6	WT/P-LOX	0.0	K FACTOR	37.3479	WTBY	0.125
DELTA PJ	201.666	TOXP	0.0			P/P	1.921
DELTA TJ	463.708	POXP	3.000				
		TFP	487.135				

SYSTEM PRESSURE LOSSES	
OB/P DIS LINE	0.296
FB/P DIS LINE	0.138
PUMP INTR STG	11.614
PUMP DIS LINE	2.413
JAC IN LINE	4.695
JAC DIS LINE	0.0
FUEL TURB IN	19.066
FUEL TURB DIS	37.026
FUEL INTR LINE	24.601
INJ IN LINE	0.0
OX TURB IN	31.645
OX TURB DIS	0.0
INJ IN LINE	

CHAMBER	
PC (INJ FACE)	915.170
IMPULSE (CHAMBER)	472.605
IMPULSE (DELIVERED)	472.197
MIXTURE RATIO(INLET)	5.500
MIXTURE RATIO(CHAMBER)	5.865
CS	0.965
ETA C*	0.994
AREA RATIO	401.000

RL10 EXTENSION OFF-DESIGN DECK

CATEGORY IV BASE CASE DATE 8-21-73 RM=6.5

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.0	PRESSURE	16.0
TEMP	36.9	TEMP	163.8
NPSP	0.0	NPSP	0.0
FLOW	4.37	FLOW	28.38

FUEL LSI		LOX LSI		FUEL PUMP (MAIN)		LOX PUMP (MAIN)	
SPEED	29881.	SPEED	2946.	SPEED	73644.	SPEED	38135.
						FLOW	28.378
FLOW	4.37	FLOW	28.38	FLOW	4.366	POWER	180.29
POWER	5.8	POWER	5.6	INLET GPM	442.7	EFF	0.6921
EFF	0.7283	EFF	0.6430	NPSP	17.48	INLET P	50.18
DISCH P	32.48	DISCH P	50.52			INLET T	164.0
RHO IN	4.405	RHO IN	70.893	* 1ST STAGE *		DISCH P	1240.66
				POWER	436.47	DISCH T	170.3
				EFF	0.5974	RHO IN	70.892
FUEL TURBINE		**LOX TURBINE**		INLET P	32.36	RHO OUT	70.959
				DISCH P	1017.65	INLET GPM	179.7
FLOW	3.785	FLOW	3.785	DISCH T	54.116	NPSP	34.05
POWER	871.70	POWER	206.72	RHO IN	4.426		
EFF	0.6706	EFF	0.7348	RHO OUT	4.315		
INLET P	1774.57	INLET P	1128.64				
INLET T	609.1	INLET T	566.1	* 2ND STAGE *			
DIS P(S)	1184.18	DIS P(S)	1029.25	POWER	451.14		
DELH ACT	162.9	DELH ACT	38.6	EFF	0.5971		
M. VEL R	0.455	M. VEL R	0.459	INLET P	1008.13		
ACD	0.405	ACD	1.025	DISCH P	1991.74		
PCT HP	97.57	PCT HP	111.20	DISCH T	71.9		
HP TRANS	15.9	P/P	1.096	RHO OUT	4.244		
P/P	1.499						

FUEL INJECTOR		LOX INJECTOR			
DELTA P	84.77	DELTA P	162.34	MIXTURE RATIO	6.500
INLET P	999.34	INLET P	1076.92	THRUST	15186.
INLET T	559.6	INLET T	170.9	IMPULSE	463.78
ACD	1.282	ACD	0.396	CHAMBER PRESSURE	914.57
MV	40.009	RHO	70.699		
		MV	28.743		

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	4.07	WLEAK	0.300	DELTA P	163.75	ACD	0.0279
INLET P	1986.00	WT/P-FUEL	0.0	ACD	0.3939	WTBY/WF	6.904
INLET T	71.9	WT/P-LOX	0.0	K FACTOR	14.4283	WTBY	0.281
DELTA PJ	194.421	TOXP	0.0			P/P	1.793
DELTA TJ	537.154	POXP	3.000				
		TFP	559.625				

SYSTEM PRESSURE LOSSES	
OB/P DIS LINE	0.339
FB/P DIS LINE	0.113
PUMP INTR STG	9.524
PUMP DIS LINE	1.947
JAC IN LINE	3.790
JAC DIS LINE	0.0
FUEL TURB IN	17.008
FUEL TURB DIS	34.361
FUEL INTR LINE	21.183
INJ IN LINE	0.0
OX TURB IN	29.913
OX TURB DIS	0.0
INJ IN LINE	

CHAMBER	
PC (INJ FACE)	914.575
IMPULSE (CHAMBER)	464.088
IMPULSE (DELIVERED)	463.775
MIXTURE RATIO(INLET)	6.500
MIXTURE RATIO(CHAMBER)	6.980
CS	0.964
ETA C*	0.989
AREA RATIO	401.000

RLIC EXTENSION OFF-DESIGN DECK

CATEGORY IV PUMPED IDLE 8-21-72

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.0	PRESSURE	16.0
TEMP	36.9	TEMP	163.8
NPSP	0.0	NPSP	0.0
FLOW	1.20	FLOW	7.19

FUEL LSI		LOX LSI		FUEL PUMP (MAIN)		LOX PUMP (MAIN)	
SPEED	12988.	SPEED	1280.	SPEED	32009.	SPEED	16575.
FLOW	1.20	FLOW	7.19	FLOW	1.199	FLOW	7.191
POWER	0.6	POWER	0.6	INLET GPM	121.6	POWER	11.45
EFF	0.5546	EFF	0.4730	NPSP	5.98	EFF	0.5990
DISCH P	20.64	DISCH P	26.89			INLET P	26.87
RHO IN	4.405	RHO IN	70.893	* 1ST STAGE *		INLET T	163.9
				POWER	32.37	DISCH P	285.09
				EFF	0.4567	DISCH T	165.6
				INLET P	20.63	RHO IN	70.886
				DISCH P	224.31	RHO OUT	70.841
				DISCH T	41.754	INLET GPM	45.5
				RHO IN	4.424	NPSP	10.84
				RHO OUT	4.330		

FUEL TURBINE		LOX TURBINE		FUEL PUMP (MAIN)	
FLOW	0.576	FLOW	0.576		
POWER	59.55	POWER	18.89		
EFF	0.5416	EFF	0.5466		
INLET P	348.10	INLET P	282.14		
INLET T	751.7	INLET T	731.0	* 2ND STAGE *	
DIS P(S)	289.51	DIS P(S)	266.32	POWER	33.51
DELH ACT	73.2	DELH ACT	23.2	EFF	0.4601
M. VEL R	0.265	M. VEL R	0.222	INLET P	223.60
ACD	0.425	ACD	1.133	DISCH P	427.12
PCT HP	89.61	PCT HP	156.72	DISCH T	47.1
HP TRANS	6.3	P/P	1.059	RHO OUT	4.238
P/P	1.202				

FUEL INJECTOR		LOX INJECTOR			
DELTA P	27.50	DELTA P	10.40	MIXTURE RATIO	6.000
INLET P	261.81	INLET P	244.71	THRUST	3750.
INLET T	737.3	INLET T	165.8	IMPULSE	446.96
ACD	1.292	ACD	0.396	CHAMBER PRESSURE	234.31
MV	13.569	RHO	70.775		
		MV	1.842		

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	1.08	WLEAK	0.122	DELTA P	40.38	ACD	0.3176
INLET P	426.71	WT/P-FUEL	0.0	ACD	0.2012	WTBY/WF	46.531
INLET T	47.1	WT/P-LOX	0.0	K FACTOR	55.3131	WTBY	0.501
DELTA PJ	76.267	TOXP	0.0			P/P	1.329
DELTA TJ	704.634	POXP	********				
		TPP	737.321				

SYSTEM PRESSURE LOSSES	
OE/P DIS LINE	0.022
FE/P DIS LINE	0.009
PUMP INTR STG	0.716
PUMP DIS LINE	0.137
JAC IN LINE	0.266
JAC DIS LINE	0.0
FUEL TURB IN	2.347
FUEL TURB DIS	4.896
FUEL INTR LINE	2.466
INJ IN LINE	0.0
OX TURB IN	4.511
OX TURB DIS	0.0
INJ IN LINE	

CHAMBER	
PC (INJ FACE)	234.305
IMPULSE (CHAMBER)	447.804
IMPULSE (DELIVERED)	446.958
MIXTURE RATIO(INLET)	6.000
MIXTURE RATIO(CHAMBER)	6.679
CS	0.950
ETA C*	0.993
AREA RATIO	401.000

PRATT & WHITNEY AIRCRAFT

Florida Research and Development Center

Category IV Engine

TANK HEAD IDLE

INLET CONDITIONS

Fuel

Pressure = 16.0 psia
Temperature = 36.9 °R
Saturated Liquid

Oxidizer

Pressure = 16.0 psia
Temperature = 163.8 °R
Saturated Liquid

Fuel Side

Flow = .04 lb/sec

Jacket Inlet Temperature =	36.9 °R
Jacket Inlet Pressure =	15.9 PSIA
Jacket Discharge Temperature =	836. °R
Jacket Discharge Pressure =	11.4 PSIA
Injector Inlet Temperature =	599. °R
Injector Inlet Pressure =	7.0 PSIA
Dump Nozzle Coolant Flow =	0.006 LB/SEC

Oxidizer Side

Flow = .15 lb/sec

Main Pump Discharge Temperature =	163.8°R
Main Pump Discharge Pressure =	15.9PSIA
Injector Inlet Temperature =	579. °R
Injector Inlet Pressure =	15.6PSIA
Injector Pressure Loss =	9.7 PSIA

Chamber Pressure =	5.9 PSIA
Thrust =	73. lb_f
Mixture Ratio =	4.0
Impulse =	385 sec
Chamber Mixture Ratio =	4.4

MODIFIED RL10 OFF-DESIGN DECK

CATEGORY I BASELINE O/F = 6.0 8-21-73

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.43	PRESSURE	19.71
TEMP	36.9	TEMP	163.8
NPSP	0.43	NPSP	3.71
FLOW	4.89	FLOW	29.34

FUEL TURBINE

FLOW	4.283
POWER	569.26
EFF	0.7267
INLET P	670.14
INLET T	438.3
DIS P(S)	494.59
DELH ACT	93.9
M. VFL R	0.415
ACD	1.074
TDIS MIX	416.29
HP TRANS	85.4
P/P	1.355

FUEL PUMP (MAIN)

SPEED	29034.
FLOW	4.890
INLET GPM	504.5

* 1ST STAGE *	
POWER	231.81
EFF	0.5361
INLET P	16.43
DISCH P	471.20
DISCH T	44.712
RHO IN	4.398
RHO OUT	4.311

* 2ND STAGE *	
POWER	251.20
EFF	0.5142
INLET P	471.20
DISCH P	911.51
DISCH T	55.9
RHO OUT	4.196

LOX PUMP (MAIN)

SPEED	. 614.
FLOW	29.340
POWER	85.45
EFF	0.6421
INLET P	19.71
INLET T	163.8
DISCH P	526.80
DISCH T	169.6
RHO IN	70.893
RHO OUT	70.152
INLET GPM	188.0

FUEL INJECTOR

DELTA P	73.98
INLET P	474.52
INLET T	416.3
ACD	1.994
MV	55.035

LOX INJECTOR

DELTA P	51.56
INLET P	452.10
INLET T	169.8
ACD	0.732
RHO	70.081
MV	16.784

MIXTURE RATIO	6.000
THRUST	14997.
IMPULSE	438.13
CHAMBER PRESSURE	400.54

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	4.82	WLEAK	0.070	DELTA P	74.71	ACD	0.1329
INLET P	872.50	WT/P-FUEL	0.0	ACD	0.6072	WTBY/WF	11.142
INLET T	55.9			K FACTOR	6.0371	WTBY	0.537
DELTA PJ	163.345					P/P	1.368
DELTA TJ	382.398						

SYSTEM PRESSURE LOSSES
****

PUMP INTR STG	0.0
PUMP DIS LINE	38.756
GAS VENTURI	36.014
JAC IN LINE	3.073
JAC DIS LINE	0.0
FUEL TURB IN	0.0
FUEL TURB DIS	9.202
INJ IN LINE	6.098

MODIFIED RL10 OFF-DESIGN DECK

CATEGORY I BASELINE O/F = 5.5 8-21-73

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.43	PRESSURE	19.71
TEMP	36.9	TEMP	163.8
NPSP	0.43	NPSP	3.71
FLOW	5.18	FLOW	28.47

FUEL TURBINE

FLOW	4.611
POWER	603.59
EFF	0.7306
INLET P	686.04
INLET T	406.7
DIS P(S)	497.80
DELH ACT	92.5
M. VEL R	0.426
ACD	1.072
TDIS MIX	385.09
HP TRANS	86.8
P/P	1.378

FUEL PUMP (MAIN)

SPEED	29478.
FLOW	5.177
INLET GPM	534.1

* 1ST STAGE *

POWER	247.71
EFF	0.5455
INLET P	16.43
DISCH P	484.10
DISCH T	44.806
RHO IN	4.398
RHO OUT	4.331

* 2ND STAGE *

POWER	268.40
EFF	0.5213
INLET P	484.10
DISCH P	937.08
DISCH T	55.9
RHO OUT	4.211

LOX PUMP (MAIN)

SPEED	11791.
FLOW	28.473
POWER	86.83
EFF	0.6349
INLET P	19.71
INLET T	163.8
DISCH P	544.50
DISCH T	169.7
RHO IN	70.893
RHO OUT	70.193
INLET GPM	182.5

FUEL INJECTOR

DELTA P	79.88
INLET P	477.41
INLET T	385.1
ACD	1.996
MV	56.003

LOX INJECTOR

DELTA P	51.92
INLET P	449.38
INLET T	169.9
ACD	0.732
RHO	69.913
MV	15.692

MIXTURE RATIO	5.500
THRUST	14867.
IMPULSE	441.80
CHAMBER PRESSURE	397.50

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	5.11	WLEAK	0.070	DELTA P	95.02	ACD	0.1140
INLET P	893.45	WT/P-FUEL	0.0	ACD	0.5221	WTBY/WF	9.074
INLET T	55.9			K FACTOR	8.2034	WTBY	0.496
DELTA PJ	168.334					P/P	1.391
DELTA TJ	350.850						

SYSTEM PRESSURE LOSSES
****

PUMP INTR STG	0.0
PUMP DIS LINE	43.350
GAS VENTURI	37.949
JAC IN LINE	3.130
JAC DIS LINE	0.0
FUEL TURB IN	0.0
FUEL TURB DIS	9.487
INJ IN LINE	6.289

MODIFIED RL10 OFF-DESIGN DECK

CATEGORY I BASELINE O/F = 6.5 8-21-73

INLET CONDITIONS

FUEL		LOX	
PRESSURE	16.43	PRESSURE	19.71
TEMP	36.9	TEMP	163.8
NPSP	0.43	NPSP	3.71
FLOW	4.69	FLOW	30.51

FUEL TURBINE

FLOW	4.076
POWER	545.37
EFF	0.7237
INLET P	660.73
INLET T	461.5
DIS P(S)	493.82
DELH ACT	94.6
M. VEL R	0.408
ACD	1.076
TDIS MIX	439.39
HP TRANS	85.2
P/P	1.338

FUEL PUMP (MAIN)

SPEED	28682.
FLOW	4.692
INLET GPM	484.1
* 1ST STAGE *	
POWER	220.22
EFF	0.5295
INLET P	16.43
DISCH P	460.40
DISCH T	44.624
RHO IN	4.398
RHO OUT	4.307
* 2ND STAGE *	
POWER	238.70
EFF	0.5075
INLET P	460.40
DISCH P	891.04
DISCH T	55.8
RHO OUT	4.186

LOX PUMP (MAIN)

SPEED	11473.
FLOW	30.508
POWER	85.17
EFF	0.6494
INLET P	19.71
INLET T	163.8
DISCH P	511.60
DISCH T	169.5
RHO IN	70.893
RHO OUT	70.213
INLET GPM	195.5

FUEL INJECTOR

DELTA P	71.69
INLET P	474.04
INLET T	439.4
ACD	1.990
MV	54.163

LOX INJECTOR

DELTA P	55.73
INLET P	458.08
INLET T	169.7
ACD	0.732
RHO	70.115
MV	17.915

MIXTURE RATIO	6.500
THRUST	15211.
IMPULSE	432.13
CHAMBER PRESSURE	402.35

JACKET		LEAKAGE & BLEED		RM CONTROL VLV		THRUST CONTROL	
FLOW	4.62	WLEAK	0.070	DELTA P	53.50	ACD	0.1420
INLET P	855.08	WT/P-FUEL	0.0	ACD	0.7458	WTBY/WF	11.821
INLET T	55.8	WT/P-LOX	0.0	K FACTOR	4.0242	WTBY	0.546
DELTA PJ	159.225					P/P	1.352
DELTA TJ	405.752						

SYSTEM PRESSURE LOSSES
****

PUMP INTR STG	0.0
PUMP DIS LINE	35.727
GAS VENTURI	32.114
JAC IN LINE	3.032
JAC DIS LINE	0.0
FUEL TURB IN	0.0
FUEL TURB DIS	8.946
INJ IN LINE	5.926

Appendix V

Maintainability Engineering Layout Reviews

During the Critical Elements Evaluation and Baseline Engine Design effort, engine design layouts were reviewed by the Design Maintainability Group to insure that maintainability requirements were adequately considered in the engine designs. Maintainability Engineering Layout Review (MELR) forms were issued to document the results of these reviews. A total of 20 MELR's and 5 supplementary MELR's were issued during this study as a result of these reviews. Of the MELR's issued, 18 are applicable to the three final baseline engine configurations selected and they are classified as "active". The others do not apply to the configurations selected and they are classified as "inactive".

Copies of all of the MELR's are included in this appendix. Section I contains all of the MELR's that apply to the Derivative IIA and IIB and Category IV engines whereas Section II contains all of the inactive MELR's that no longer apply to the baseline engines in their present configuration. MELR's are included in this appendix for the following engine component layouts:

Section I. Active MELR's (i.e. those applicable for the final baseline engines)

Oxidizer Boost Pump (Layout #228068) - Applicable to RL10 Derivative IIA engine.

Two Position Nozzle (Layout #228113) - Applicable to RL10 Derivative II and Category IV engines.

Two Position Nozzle Seal (Layout #228303) - Applicable to RL10 Derivative II and Category IV engines.

Two Position Nozzle Brake and Disconnect Valve (Layout #228330) - Applicable to RL10 Derivative II and Category IV engines.

GO_2 Heat Exchanger (Layout #228365) - Applicable to RL10 Derivative II and Category IV engines.

Two Position Nozzle Seal (Layout #228367) - Applicable to RL10 Derivative II and Category IV engines.

Turbopump (Layout #228398) - Applicable to RL10 Category IV engine with RL10 Derivative IIA interfaces.

Turbopump (Layout #228398) - Applicable to RL10 Category IV engine with minimum power head diameter.

RL10 Category IV Engine Installation (Layout #228401) - Applicable to Category IV engine.

Primary Nozzle (Layout #228402) - Applicable to RL10 Derivative II engines.

RL10 Derivative IIA Engine Installation (Layout#228412) - Applicable to RL10 Derivative IIA engine.

RL10 Derivative IIB Engine Installation (Layout#228413) - Applicable to RL10 Derivative IIB engine.

Turbopump (Layout #228436) - Applicable to RL10 Derivative IIA engine.

Valves (Layout #228480) - Applicable to RL10 Derivative II and Category IV engines.

Quick Disconnect Valve (Layout #228368) - Applicable to RL10 Derivative II and Category IV engines.

Section II. Inactive MELR's (i.e. those not applicable to the baseline engines in their present configuration)

GO_2 Heat Exchanger (Layout #228062) - Applicable to RL10 Derivative II and Category IV engines.

GH_2 Driven Low Speed Inducer (Layout #228118) - Applicable to RL10 Derivative IIA and Category IV engines.

Appendix V

Section I

Copies of Active Maintainability Engineering Layout Review Forms

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIVATIVE IIA PAGE 1 OF 5

LAYOUT NO. 228068 TITLE OXIDIZER BOOST PUMP SCHEME
SHT. 1 OF 1 CHG. NC DESIGNER D. TRENSCHEL
REVIEWED BY W. QUIGLEY EXT. 3240 DATE 5-10-73

INTENT: PROVIDE A CONCEPTUAL DESIGN OF A GEAR DRIVEN BOOST PUMP.

OXIDIZER BOOST PUMP

(1) THE GEAR AND SHAFT TIEBOLT REQUIRES A TABWASHER SAFETY LOCK.

(2) THE BRG AND SEAL SLEEVE WILL REQUIRE A PULLER GROOVE TO FACILITATE DISASSEMBLY.

(3) THE IMPELLER SEAL RING IS A SEPARATE PART AND IT IS EASILY REPLACED IF DAMAGED.

(4) IT APPEARS THAT THE BOOST PUMP CAN BE SEPARATED FROM THE G'BOX WITHOUT TO MUCH TROUBLE.

MAIN OXIDIZER PUMP

(5) IT APPEARS THAT THE PUMP AND G'BOX MUST BE REMOVED AS AN ASSEMBLY.

(6) THE PLANETARY GEAR BRG SHAFTS SHOULD HAVE EXTERNAL WRENCHING FLATS TO FACILITATE ASSY, AND THE BRG I.D. RACE SPACERS SHOULD BE PART OF THE PLATE, (BRAZE OR WELD IN PLACE).

FOLLOW UP

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIV. PAGE 2 OF 5

LAYOUT NO. 228068 TITLE
SHT. ____ OF ____ CHG. ____ DESIGNER
REVIEWED BY W. QUIGLEY EXT. ____ DATE ____

(7) THE PLANETARY GEARS CAN BE INSTALLED BACKWARDS, SEE SKETCH.

(8) THE PLANETARY GEAR BRG'S SHOULD BE SYMMETRICAL SO THEY CAN BE INSTALLED EITHER WAY AND A PULLER GROOVE SHOULD BE INCLUDED TO FACILITATE REMOVAL.

(9) THE PUMP SHAFT GEAR CAN BE INSTALLED UPSIDE DOWN, FOOLPROOFING IS NEEDED (STEP DIA'S). A PULLER GROOVE OR THREADED HOLES SHOULD ALSO BE INCLUDED FOR REMOVAL. (SEE SKETCH)

(10) THE ROLLER BRG'S CAN BE INSTALLED UPSIDE DOWN, FOOLPROOFING IS NEEDED, AND PULLER GROOVES SHOULD BE INCLUDED TO FACILITATE BRG REMOVAL.

(11) THE G'BOX IDLER GEAR IS FOOLPROOFED BY CONFIGURATION. IF IT IS INSTALLED UPSIDE DOWN THERE IS CONSIDERABLE INTERFERENCE BETWEEN THE GEAR AND THE HSG.

(12) THE PUMP BALL BRG CAN BE INSTALLED UPSIDE DOWN, FOOLPROOFING IS NEEDED. A PULLER GROOVE IS NEEDED TO FACILITATE REMOVAL.

FOLLOW UP

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIV

LAYOUT NO. 228068 TITLE
SHT. ___ OF ___ CHG. ___ DESIGNER
REVIEWED BY W. QUIGLEY EXT. ___ DATE ___

(13) THE PUMP INDUCER LAB SEAL LAND RING SHOULD HAVE A PULLER GROOVE OR THREADED HOLES FOR DISASSEMBLY.

GENERAL COMMENTS

(14) PUMP HOUSINGS ARE FOOLPROOFED BY CONFIGURATION.

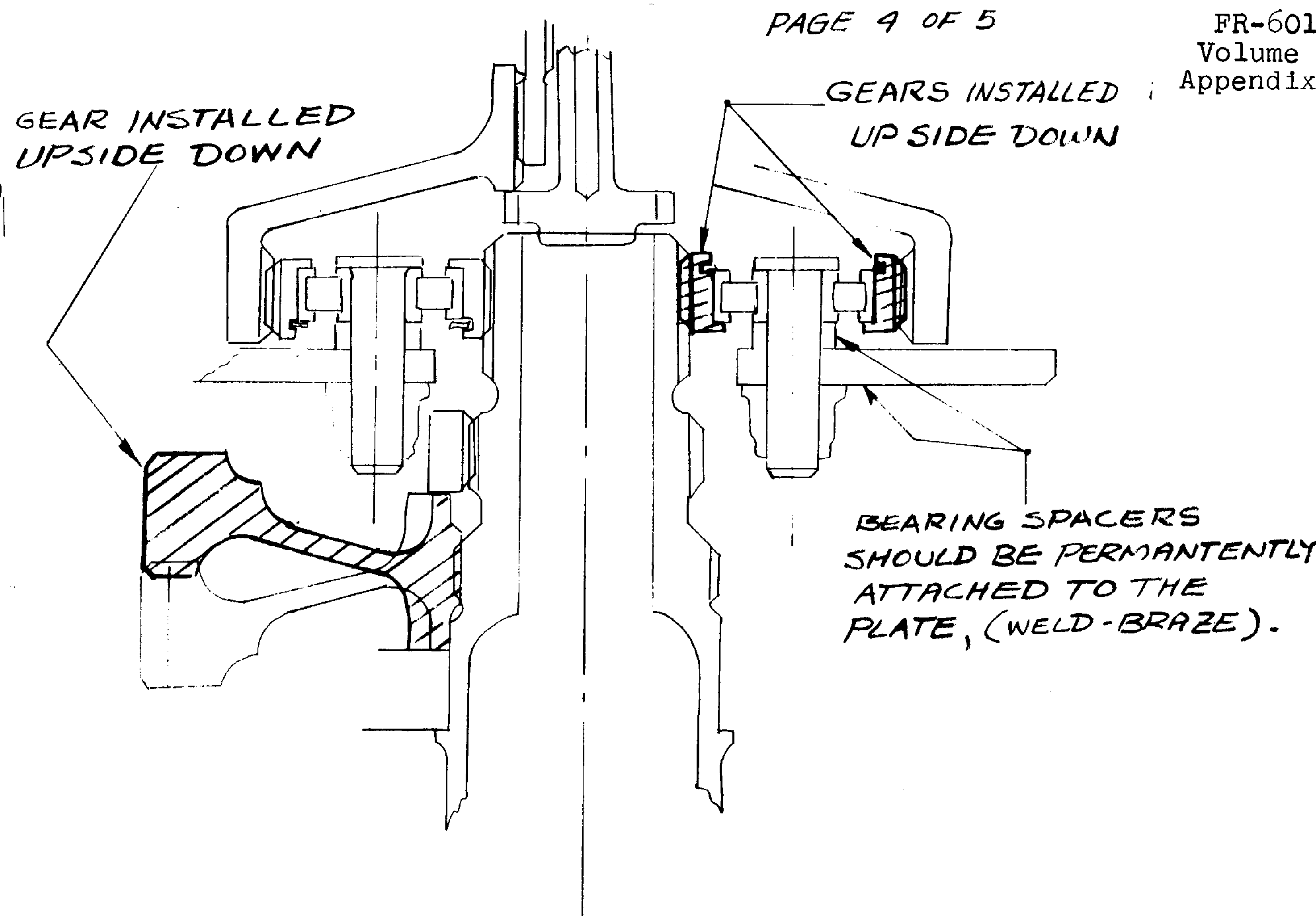
(15) PUMP IMPELLERS ARE FOOLPROOFED BY CONFIGURATION. REMOVAL FEATURE SHOULD BE INCLUDED, (PULLER GROOVE OR HOLES).

(16) SEAL PACKAGE STACKS SHOULD BE FOOLPROOFED TO PREVENT MISASSEMBLY.

(17) ELIMINATE THE RIVET LOCK AND USE A TAB LOCK SAFETY ON THE BRG RETAINER RING.

FOLLOW UP

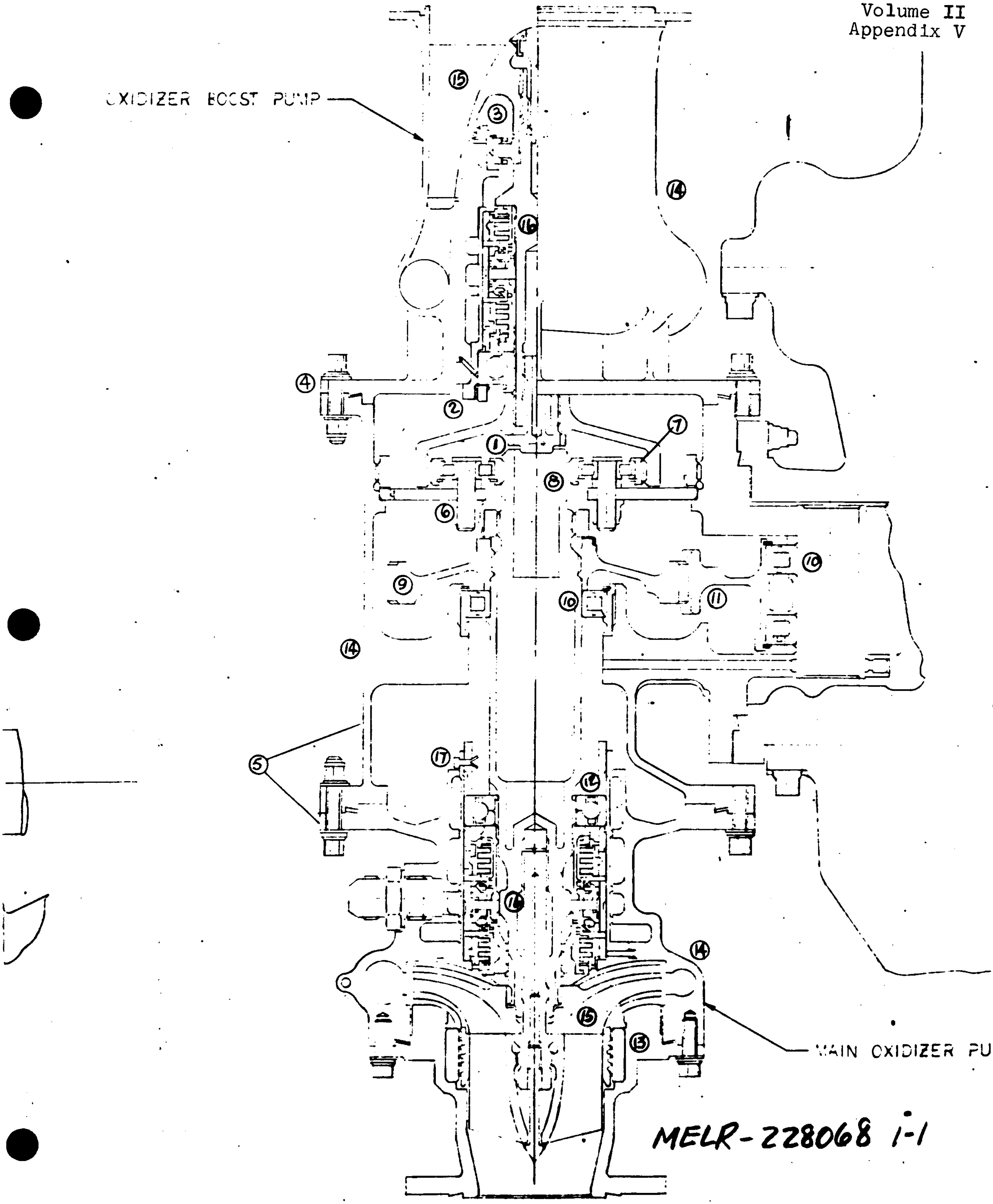
PWA 10696D Rev. 10-71



MELR - 228068 1-1

W. QUIGLEY

5-10-73



MELR-228068 i-1

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL [illegible] DERIVATIVE IIA   PAGE 1 of 1

LAYOUT NO. 228068   TITLE OXIDIZER BOOST PUMP SCHEME
SHT. 1 OF 1   CHG. NC   DESIGNER D. TRENSCHEL
REVIEWED BY W. QUIGLEY   EXT. 2240   DATE 8-15-72

= SUPPLEMENT COPY =

1) PROVIDE ACCESS FOR INTERNAL BORESCOPE INSPECTION OF BEARINGS AND GEARING.

2) PROVIDE ACCESS TO ALLOW FOR A MANUAL TORQUE CHECK OF PUMP GEAR TRAINS.

THE ABOVE ESSENTIAL INSPECTION REQUIREMENTS ARE TO BE ACCOMPLISHED WITH THE ENGINE INSTALLED IN THE SPACE TUG VEHICLE.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL 10 DERIVATIVE IIA, IIB, & IV PAGE 1 OF 3

LAYOUT NO. 228113 TITLE ADVANCED RL10 (CAT II) TWO POSITION NOZZLE
SHT. — OF — CHG. NC DESIGNER R. J. ROETMAN
REVIEWED BY W. QUIGLEY EXT. 3240 DATE 5-2-73

SHEET 1 OF 2 NO APPARENT MAINTAINABILITY PROBLEMS. MORE DETAILED INFORMATION PROVIDED ON SHEET 2.

SHEET 2 OF 2

LAYOUT SECTION A-A

1.) THE BALL BEARINGS SHOULD BE COMMON FOR BOTH CONNECTIONS, THEY SHOULD BE SYMMETRICAL SO THEY CAN BE INSTALLED EITHER WAY AND PULLER GROOVES SHOULD BE PROVIDED FOR EASY REMOVAL.
2.) THE SEALS SHOULD BE COMMON FOR BOTH CONNECTIONS.
3.) THE HOUSING SHOULD HAVE WRENCHING PROVISIONS SO IT CAN BE HELD SAFELY WHILE THE COVER IS BEING TORQUED.
4.) ELIMINATE THE BRG I.R. SPANNER NUT, LOCK WASHER, AND THREADS AND USE A RETAINING RING AS SHOWN IN THE OPPOSITE CONNECTION, THIS WOULD HELD REDUCE COST AND IMPROVE LOGISTICS.
5.) THE LIP SEAL SHOULD BE COMMON TO ALL LOCATIONS.
6.) THE SPACER SHOULD BY SYMMETRICAL SO IT CAN BE INSTALLED EITHER WAY AND PULLER GROOVES SHOULD BE PROVIDED IF REQUIRED FOR DISASSEMBLY.

FOLLOW UP

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL 10 PAGE 2 OF 3

LAYOUT NO. 228113 TITLE
SHT. ___ OF ___ CHG. ___ DESIGNER
REVIEWED BY W. QUIGLEY EXT. ___ DATE ___

LAYOUT SECTION B-B & C-C

1) PROVIDE PULLER GROOVE ON INNER SUPPORT IF REQUIRED FOR DISASSEMBLY.
2) THE SPACERS SHOULD BE SYMMETRICAL AND PULLER GROVES SHOULD BE ADDED IF REQUIRED.
3) ELIMINATE SPLIT RINGS AND USE A "V" BAND MARMON TYPE CLAMP.
4) A CASELLATED SPANNER NUT SHOULD BE USED TO IMPROVE TOOL ACCESS AND THE PINNED LOCK SHOULD BE REPLACED WITH A TABWASHER SAFETY WHICH IS EASIER AND FASTER.

VIEW K

1) ELIMINATE THE SPACERS BETWEEN THE BRG RACES AND THE SPANNER NUTS.
2) THE BRGS SHOULD BE COMMON TO BOTH ENDS OF THE BALL SCREW, THEY SHOULD BE SYMMETRICAL SO THEY CAN BE INSTALLED IN EITHER POSITION AND PULLER GROOVES SHOULD BE ADDED TO FACILITATE REMOVAL.
3) THE BRG SPANNER NUTS WILL REQUIRE A TABWASHER LOCK.

FOLLOW UP

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 PAGE 3 OF 3

LAYOUT NO. 228113 TITLE
SHT. ___ OF ___ CHG. ___ DESIGNER
REVIEWED BY W. QUIGLEY EXT. ___ DATE ___

4) THE BRG I.R. SHOULD BE RETAINED WITH A RING, SAME AS VIEW L. THIS WOULD ELIMINATE THE SPANNER NUT, TAB WASHER, AND THREADS, (REDUCE COST, IMPROVE LOGISTICS).

VIEW L

1) THE SPANNER NUTS WILL REQUIRE A TABWASHER LOCK.
2) THE BRG O.R. SPANNER NUT HAS VERY POOR TOOLING ACCESS. A CASELLATED NUT WOULD IMPROVE WRENCH ACCESS.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIVATIVE IIA, IIB & IV PAGE 1 OF 1

LAYOUT NO. 228303 TITLE SEAL-EXTEND. NOZZLE
SHT. 1 OF 1 CHG. NC DESIGNER J.L. PAPPIN
REVIEWED BY W. QUIGLEY EXT. 3240 DATE 6-6-73

INTEND: PROVIDE AN INPROVED EXTENDIBLE NOZZLE SEAL FOR THE ADVANCED RL-10 CAT II ROCKET ENGINE.

1.) THREE SCHEMES IN ORDER OF PREFERENCE.

SCHEME I (BOLTS & LOCKNUTS).
- (a) SEAL COMPONENTS ARE EASILY REPLACED.
- (b) USE TAB LOCKS ON SEAL RING PLATE BOLTS.

SCHEME III (BOLTS)
- (a) SEAL COMPONENTS ARE EASILY REPLACED.
- (b) USE TAB LOCKS ON SEAL RING PLATE BOLTS.
- (c) SEAL SUPPORT RETENTION BOLTS THREAD INTO TAPPED HOLES WHICH ARE DIFFICULT TO REPAIR IF THEY ARE DAMAGED.

SCHEME II (RIVETS)
- (a) RIVETED CONSTRUCTION MAKES SEAL REPLACEMENT MORE DIFFICULT THAN A BOLTED SCHEME.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIVATIVE IIA, IIB, IV
TITLE NOZZLE QUICK DISCONNECT - SOLENOID ACTUATED SYSTEM BRAKE STUDY
PAGE 1 OF 4
LAYOUT NO. 228330
SHT. 1 OF 1 CHG. NC
DESIGNER GORDON STEPPENS
REVIEWED BY W. QUIGLEY
EXT. 3240
DATE 6-7-73

SOLENOID ACTUATED BRAKE

1) SOLENOID ACTUATED BRAKE WILL BE A PURCHASED VENDOR ASSEMBLY.

(a) IT APPEARS THAT THE TWO SOLENOIDS ARE WIRED IN PARALLEL WHICH COULD CAUSE MISALIGNMENT OF THE BAR IF ONE SOLENOID MALFUNCTIONS. SUGGEST THE SOLENOIDS BE WIRED IN SERIES EITHER CONCENTRIC OR INLINE ONE BEHIND THE OTHER. (SEE ATTACHED SKETCH)

(b) ADDITIONAL INFORMATION IS REQUIRED IF A COMPREHENSIVE MAINTAINABILITY ASSESSMENT IS TO BE MADE. THE FOLLOWING AREAS WILL BE REVIEWED WHEN THE DESIGN IS FIRM.

1) MOUNTING - ACCESS FOR CHECKOUT & REPLACEMENT
2) ELECTRICAL CONNECTIONS
3) REPAIR CONSIDERATIONS.

- CONTINUED -

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIVATIVE

LAYOUT NO. 228330 TITLE

SHT. ____ OF ____ CHG. ____ DESIGNER

REVIEWED BY W. QUIGLEY EXT. ____ DATE 6-7-73

QUICK DISCONNECT SCHEME

1) THERE APPEARS TO BE ADEQUATE LEAD IN TO ENABLE THE TUBE TO BE PROPERLY SEATED WHEN THE NOZZLE IS EXTENDED.

2) IT APPEARS THAT THE PARTS ARE FOOLPROOFED BY CONFIGURATION.

   (a) SEALS SHOULD BE COMMON TO FIT BOTH SIDES OF SPHERICAL SEAL JOINT.

   (b) SPHERICAL SEAL SEATS SHOULD BE COMMON TO BOTH SIDES.

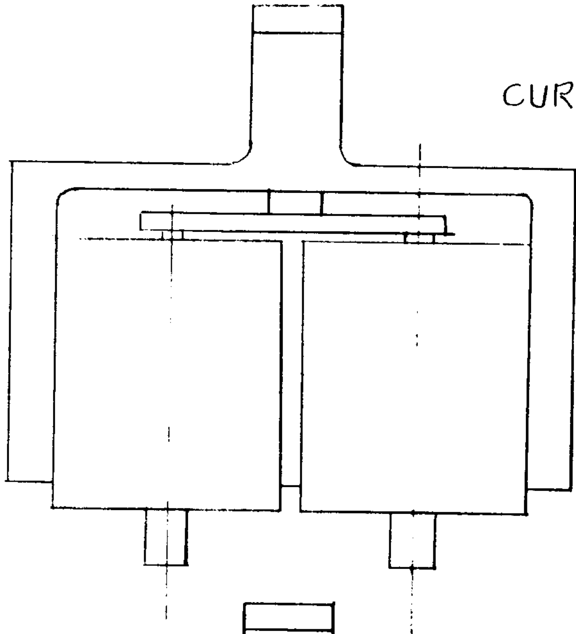
3) USE BOLTS AND SELF LOCKING NUTS ON SEAL FLANGE.

= SEE PAGE 4 FOR ITEM CALL-OUT =

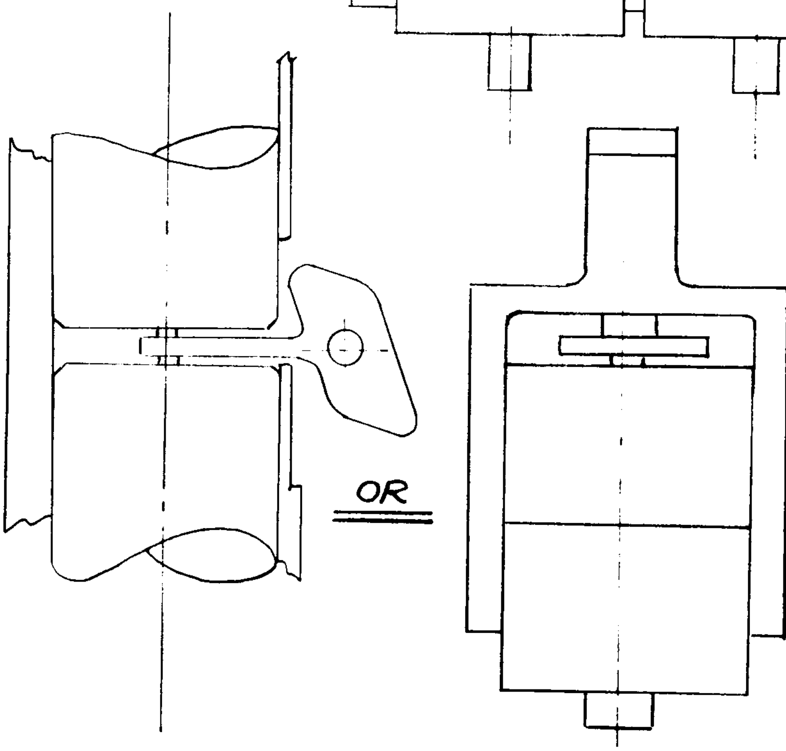
FOLLOW UP

PWA 10696D Rev. 10-71

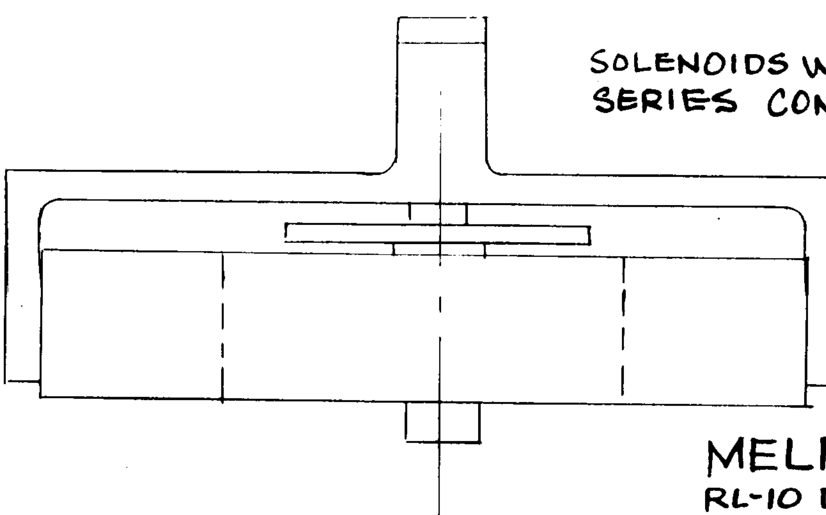
CURRENT DESIGN



SOLENOIDS WIRED IN SERIES IN-LINE OR IN-LINE OPPOSING



SOLENOIDS WIRED IN SERIES CONCENTRIC



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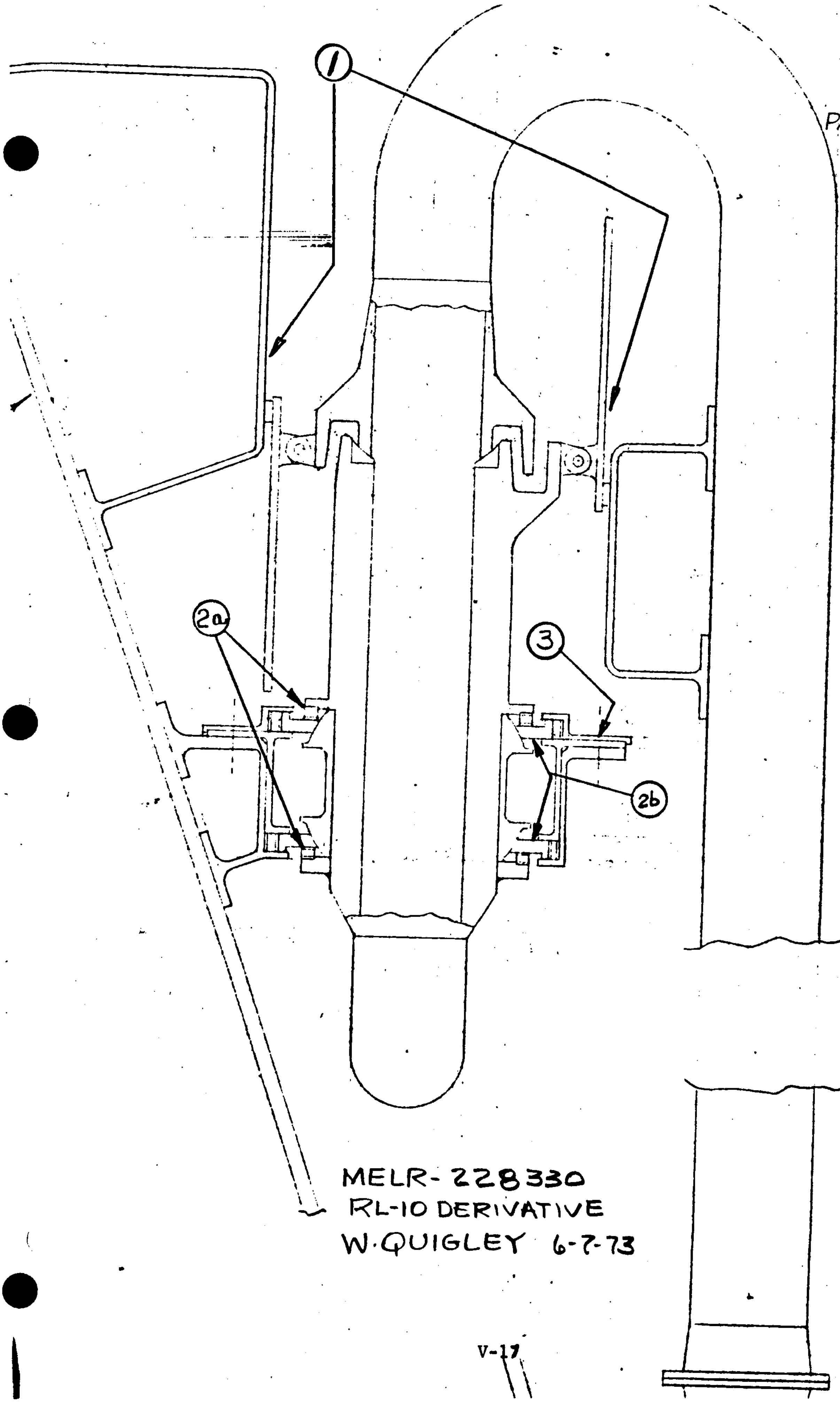
RL-10 DERIVATIVE
W. QUIGLEY 6-7-73



MELR-228330
RL-10 DERIVATIVE
W. QUIGLEY 6-7-73

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIVATIVE IIA, IIB & III COMPACT H_2-O_2 PAGE 1 OF 1

LAYOUT NO. 228365 TITLE HEAT EXCH. RL10 CATEGORY II

SHT. 1 OF 1 CHG. NC DESIGNER R. M. LOWMAN

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 6-12-73

INTENT: PROVIDE A COMPACT H_2-O_2 HEX FOR THE RL10 CAT II ENGINE.

1) IT APPEARS THAT THE HEX CAN BE INSTALLED BACKWARDS. FOOLPROOFING IS REQUIRED, i.e. USE DIFFERENT SIZE FLANGES OR OFF-SET FLANGES TO PREVENT MISASSEMBLY.

2) ADDITIONAL INFORMATION IS REQUIRED IF A COMPREHENSIVE MAINTAINABILITY ASSESSMENT IS TO BE MADE. THE FOLLOWING AREAS WILL BE REVIEWED WHEN THE DESIGN IS FIRM.
   (a) TUBE TO HEX FLANGE FASTENERS (BOLTS & LOCKNUTS).
   (b) HEX MOUNTING PROVISIONS FOR ACCESSIBILITY AND EASE OF REPLACEMENT.
   (c) REPAIR CONSIDERATIONS.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIVATIVE IIA, IIB, IV PAGE 1 OF 2

LAYOUT NO. 228367 TITLE EXTENDIBLE NOZZLE SEAL SCHEME
SHT. 1 OF 1 CHG. NC DESIGNER W. EASTMAN
REVIEWED BY W. QUIGLEY EXT. 3240 DATE 8-24-73

INTENT: PROVIDE A NOZZLE SEAL SCHEME FOR THE RL-10 CAT IV ENGINE.

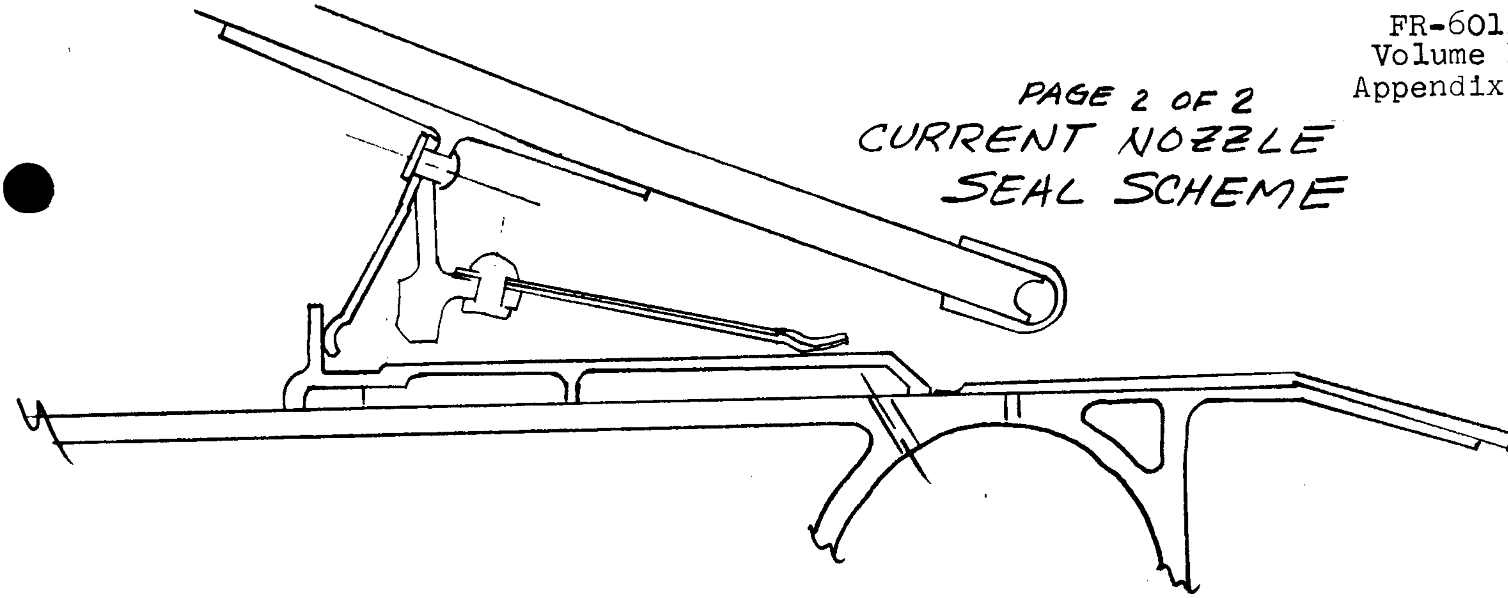
1) THE CONCENTRIC SEAL RINGS SHOULD BE SEGMENTED TO FACILITATE REPAIR. THE DAMAGED SEGMENT CAN BE REPLACED IN STEAD OF REPLACING A COMPLETE RING SEAL.

2) THE SEAL CONFIGURATION PREVENTS REMOVAL OF THE EXTEDNIBLE NOZZLE FROM THE REAR OF THE ENGINE. TO REPLACE THE NOZZLE THE ENGINE MUST BE REMOVED AND THE EXTENDIBLE NOZZLE IS TRANSLATED FORWARD OVER THE POWER HEAD. DESIGN SHOULD INVESTIGATE THE POSSIBILITY OF A SEAL WHICH WOULD ALLOW THE NOZZLE TO BE REPLACED FROM THE REAR WITHOUT ENGINE REMOVAL. SEE ATTACHED SKETCH.

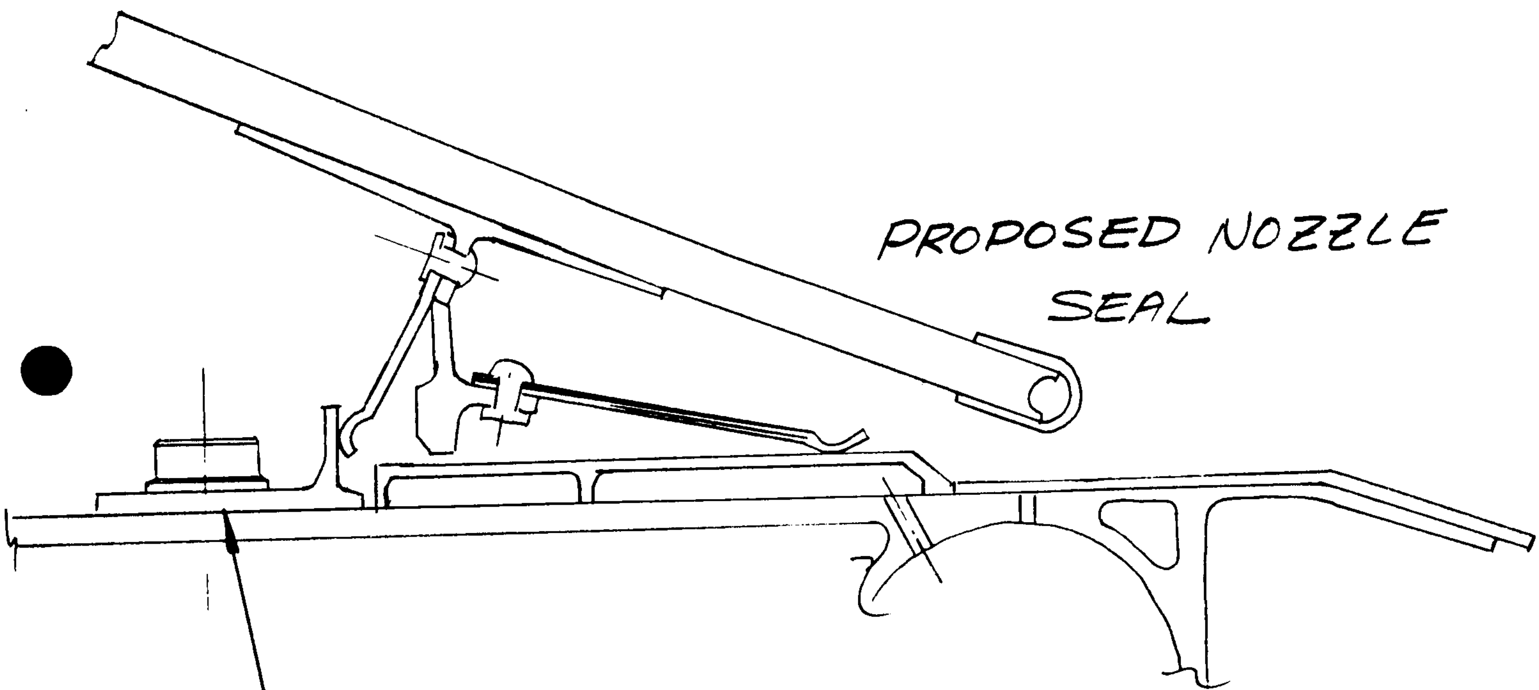
FOLLOW UP

PWA 10696D Rev. 10-71

CURRENT NOZZLE SEAL SCHEME



PROPOSED NOZZLE SEAL



REMOVAL OF THIS SEAL RING WOULD ALLOW THE NOZZLE TO BE REMOVED FROM THE BACK WITHOUT ENGINE REMOVAL.

MELR 228367 1-1
W. QUIGLEY
8-24-73

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVES CAT IV PAGE 1 OF 1

LAYOUT NO. 228398 TITLE G/B BOOST & MAIN PUMP CONFIGURATIONS WITH RL10 CAT II-A INSTALLATION INTERFACES

SHT. 1 OF 3 CHG. NC DESIGNER W. FRANCIS

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 7-25-73

INTENT: PROVIDE PRELIMINARY CONF'S FOR MAIN & BOOST OX & FUEL PUMPS & INTERCONNECTING G'BOX HAVING FUEL & OX INLET DIM'S IDENTICAL TO CAT II-A. THE G'BOX ENCLOSES A GEARTRAIN WHICH ALLOWS THE FUEL & LOX LSI'S TO BE DRIVEN BY THE MAIN LOX PUMP & WHICH PROVIDES A SYNC. IDLER GEAR BETWEEN THE MAIN PUMPS.

1) ADDITIONAL INFORMATION IS REQUIRED IF A COMPREHENSIVE MAINTAINABILITY ASSESSMENT IS TO BE MADE. THE FOLLOWING AREAS WILL BE REVIEWED WHEN THE DESIGN IS FIRM.
   (a) ADEQUATE ACCESS TO THE PUMPS TO PERMIT REPAIR AND/OR REPLACEMENT.
   (b) FOOLPROOFING PROVISIONS.
   (c) REPAIR CONSIDERATIONS i.e, KE SEAL REPLACEMENT, BEARING REPLACEMENT, ETC.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVE CAT IV PAGE 1 OF 1

LAYOUT NO. 228398 TITLE G/B, BOOST & MAIN PUMP CONFIG'S WITH RL10 CAT II-A INST. INTERFACES.

SHT. 1 OF 3 CHG. NC. DESIGNER W. FRANCIS

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 3-15-73

= SUPPLEMENT COPY =

1) PROVIDE ACCESS FOR INTERNAL BORESCOPE INSPECTION OF BEARINGS AND GEARING.

2) PROVIDE ACCESS TO ALLOW FOR A MANUAL TORQUE CHECK OF PUMP GEAR TRAINS.

THE ABOVE ESSENTIAL INSPECTION REQUIREMENTS ARE TO BE ACCOMPLISHED WITH THE ENGINE INSTALLED IN THE SPACE TUG VEHICLE.

FOLLOW UP

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVES CAT IV G/B, BOOST & MAIN PUMP A.S.E. HOUSING CONFIG'S PAGE 1 OF 1

LAYOUT NO. 228398 TITLE WITH RL10 CAT II-A INSTALLATION INTERFACES

SHT. 3 OF 3 CHG. NC DESIGNER W. FRANCIS

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 7-25-73

INTENT: PROVIDE PRELIMINARY CONFIG'S FOR FUEL & OX, MAIN & BOOST PUMPS & AN INTERCONNECTING G'BOX HAVING FUEL & OX INLETS LOCATED AT CAT II A INLET DIMENSIONS. THE G'BOX ENCLOSES GEARTRAINS FOR DRIVING THE FUEL & OXIDIZER LSI'S FROM THE OX TURBOPUMP & FOR SYNC'G THE FUEL & OX MAIN PUMPS. THE MAIN PUMP HOUSING CONIG'S ARE BASED UPON A.S.E. PUMP HSG'S MODIFIED TO REFLECT THE REV'D TURB. & IMPELLER ELEVATIONS OF CAT IV.

1) ADDITIONAL INFORMATION IS REQUIRED IF A COMPREHENSIVE MAINTAINABILITY ASSESSMENT IS TO BE MADE. THE FOLLOWING AREAS WILL BE REVIEWED WHEN THE DESIGN IS FIRM.
   (a) ADEQUATE ACCESS TO THE PUMPS TO PERMIT REPAIR AND/OR REPLACEMENT.
   (b) FOOLPROOFING PROVISIONS.
   (c) REPAIR CONSIDERATIONS i.e, KE SEAL REPLACEMENT, BEARING REPLACEMENT, ETC.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVE CAT IV PAGE 1 OF 1

LAYOUT NO. 228398 TITLE G/B, BOOST & MAIN PUMP ASE HSG CONFIG'S WITH RL10 CAT II-A INST. INTERFACES

SHT. 3 OF 3 CHG. NC. DESIGNER W. FRANCIS

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 8-15-73

= SUPPLEMENT COPY =

1) PROVIDE ACCESS FOR INTERNAL BORESCOPE INSPECTION OF BEARINGS AND GEARING.

2) PROVIDE ACCESS TO ALLOW FOR A MANUAL TORQUE CHECK OF PUMP GEAR TRAINS.

THE ABOVE ESSENTIAL INSPECTION REQUIREMENTS ARE TO BE ACCOMPLISHED WITH THE ENGINE INSTALLED IN THE SPACE TUG VEHICLE.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

CAT IV

MODEL RL10 DERIVATIVE G/B BOOST & MAIN PUMP CONFIGURATIONS WITH PAGE 1 OF 1

LAYOUT NO. 228398 TITLE MINIMUM RADIAL INSTALLATION DIMENSIONS

SHT. 2 OF 3 CHG. NC DESIGNER WOODIE FRANCIS

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 7-25-73

INTENT : PROVIDE PRELIMINARY CONCEPTUAL CONFIG'S FOR G'BOXES HAVING MINIMAL RADIAL ENVELOPE PROJECTIONS. THE G'BOX IS TO ENCLOSE A GEARTRAIN WHICH ALLOWS THE OXIDIZER TURBOPUMP TURB. TO DRIVE THE LSI'S & WHICH PROVIDES A SYNC. IDLER GEAR BETWEEN THE MAIN PUMPS.

1) ADDITIONAL INFORMATION IS REQUIRED IF A COMPREHENSIVE MAINTAINABILITY ASSESSMENT IS TO BE MADE. THE FOLLOWING AREAS WILL BE REVIEWED WHEN THE DESIGN IS FIRM.
   (a) ADEQUATE ACCESS TO THE PUMPS TO PERMIT REPAIR AND/OR REPLACEMENT.
   (b) FOOLPROOFING PROVISIONS.
   (c) REPAIR CONSIDERATIONS i.e, KE SEAL REPLACEMENT, BEARING REPLACEMENT, ETC.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL SUD DERIVATIVE CAT IV | PAGE 1 OF 1

LAYOUT NO. 228398-2 TITLE G/B, BOOST, & MAIN PUMP CONFIG'S WITH MINIMUM RADIAL INST. DIM'S
SHT. 2 OF 3 CHG. NC. DESIGNER W. FRANCIS
REVIEWED BY W. QUIGLEY EXT. 3240 DATE 8-15-72

= SUPPLEMENT COPY =

1) PROVIDE ACCESS FOR INTERNAL BORESCOPE INSPECTION OF BEARINGS AND GEARING.

2) PROVIDE ACCESS TO ALLOW FOR A MANUAL TORQUE CHECK OF PUMP GEARTRAINS.

THE ABOVE ESSENTIAL INSPECTION REQUIREMENTS ARE TO BE ACCOMPLISHED WITH THE ENGINE INSTALLED IN THE SPACE TUG VEHICLE.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVE CAT IV RL10 CAT IV PAGE 1 OF 1

LAYOUT NO. 228401 TITLE INSTALLATION DWG

SHT. 1 OF 1 CHG. NC DESIGNER G STEPPENS

REVIEWED BY W. QUIGLEY EXT. 3290 DATE 6-19-73

1) WHEN THE NOZZLE SKIRT IS IN THE STOWED OR RETRACTED POSITION, ACCESS TO THE ENGINE PUMPS, VALVES, AND PLUMBING IS BLOCKED.
IT APPEARS THAT THE TUG WOULD HAVE TO BE REMOVED FROM THE SHUTTLE AND THE NOZZLE SKIRT EXTENDED BEFORE INSPECTION AND COMPONENT REPLACEMENT MAINTENANCE TASKS CAN BE ACCOMPLISHED.

2) WHEN THE ENGINE/TUG INTERFACE IS MORE CLEARLY DEFINED THE FOLLOWING AREAS WILL BE REVIEWED FOR IMPACT ON MAINTAINABILITY.
   (a) ACCESS TO MAIN FUEL AND OXIDIZER INLET LINE CONNECTIONS.
   (b) ACCESS TO ENGINE MOUNTING POINT CONNECTIONS.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL 10 DERIVATIVE IIA, IIB

LAYOUT NO. 228402 TITLE PRIMARY NOZZLE PRELIM. DESIGN
SHT. 1 OF 1 CHG. NC DESIGNER W. EASTMAN
REVIEWED BY W. QUIGLEY EXT. 3240 DATE 6-19-73

INTENT: PROVIDE A PRELIMINARY DESIGN OF THE PRIMARY NOZZLE FOR THE RL-10 DERIVATIVE II ENGINE.

1) REF. VIEW "G," BALLSCREW GEARBOX CUT-OUTS SHOW THREADED WELDED ON BOSSES WHICH ARE DIFFICULT TO REPAIR IF THEY ARE DAMAGED. SUGGEST USING RIVETED ON NUT PLATES TO FACILITATE REPAIR OF THE NOZZLE.

2) THE SHEET METAL NOZZLE SEALS ARE READILY REPLACEABLE IF THEY BECOME WORN OR DAMAGED.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVE IIA PAGE 1 OF 1

LAYOUT NO. 228412 TITLE RL10 DERIVATIVE IIA INSTALLATION DWG

SHT. 1 OF 1 CHG. NC DESIGNER R. LOWMAN

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 6-21-73

INTENT: PROVIDE A PRELIMINARY INSTALLATION DRAWING OF THE RL10 DERIVATIVE **IIA** ENGINE.

1) WHEN THE NOZZLE SKIRT IS IN THE STOWED OR RETRACTED POSITION, ACCESS TO THE ENGINE PUMPS, VALVES, AND PLUMBING IS BLOCKED. THE NOZZLE SKIRT MUST BE PUT IN THE EXTENDED POSITION BEFORE INSPECTION AND/OR COMPONENT REPLACEMENT MAINTENANCE TASKS CAN BE ACCOMPLISHED.

2) WHEN THE ENGINE/TUG INTERFACE IS MORE CLEARLY DEFINED THE FOLLOWING AREAS WILL BE REVIEWED FOR IMPACT ON MAINTAINABILITY.
   (a) ACCESS TO MAIN FUEL AND OXIDIZER INLET LINE CONNECTIONS.
   (b) ACCESS TO ENGINE MOUNTING POINT CONNECTIONS.
   (c) ACCESS TO AND REPLACEMENT ENVELOPES FOR ENGINE COMPONENTS.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVE IIB PAGE 1 OF 1

LAYOUT NO. 228413 TITLE RL10 DERIVATIVE IIA INSTALLATION TUG

SHT. 1 OF 1 CHG. NC DESIGNER D. LOWMAN

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 6-21-73

INTENT: PROVIDE A PRELIMINARY INSTALLATION DRAWING OF THE RL10 DERIVATIVE IIB ENGINE.

1) WHEN THE NOZZLE SKIRT IS IN THE STOWED OR RETRACTED POSITION, ACCESS TO THE ENGINE PUMPS, VALVES, AND PLUMBING IS BLOCKED. THE NOZZLE SKIRT MUST BE PUT IN THE EXTENDED POSITION BEFORE INSPECTION AND/OR COMPONENT REPLACEMENT MAINTENANCE TASKS CAN BE ACCOMPLISHED.

2) WHEN THE ENGINE/TUG INTERFACE IS MORE CLEARLY DEFINED THE FOLLOWING AREAS WILL BE REVIEWED FOR IMPACT ON MAINTAINABILITY.
   (a) ACCESS TO MAIN FUEL AND OXIDIZER INLET LINE CONNECTIONS.
   (b) ACCESS TO ENGINE MOUNTING POINT CONNECTIONS.
   (c) ACCESS TO AND REPLACEMENT ENVELOPES FOR ENGINE COMPONENTS.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVE CAT IIA PAGE 1 OF 4

LAYOUT NO. 228436 TITLE BACK TO BACK OXIDIZER LSI AND TURBOPUMP

SHT. 1 OF 1 CHG. NC DESIGNER WOODIE FRANCIS

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 8-10-73

INTENT: PROVIDE A PRELIMINARY CONCEPTUAL DESIGN FOR A BACK TO BACK OXIDIZER LSI & TURBOPUMP FOR THE RL10 CAT. II A.

1) THE IDLER GEAR CAN BE INSTALLED BACKWARDS. SEE SKETCH.

2) THE OXIDIZER INLET INDUCER AND IMPELLER ARE FOOLPROOFED BY CONFIGURATION.

3) THE OXIDIZER MAIN PUMP BALL BEARING SHOULD HAVE A PULLER GROOVE TO FACILITATE DISASSEMBLY.

4) THE OXIDIZER PUMP GEAR IS FOOLPROOFED BY CONFIGURATION.

5) THE COUPLING SHAFT IS FOOLPROOFED BY CONFIGURATION, AND IT IS EASILY REPLACED IF DAMAGED.

6) THE COUPLING SHAFT ROLLER BEARING OUTER RACE SHOULD HAVE A PULLER GROOVE TO FACILITATE RACE REMOVAL.

FOLLOW UP

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVE CAT. II A PAGE 2 OF 4

LAYOUT NO. 228436 TITLE

SHT. 1 OF 1 CHG. DESIGNER

REVIEWED BY W. QUIGLEY EXT. DATE

7.) THE OXIDIZER BOOST PUMP IMPELLER IS FOOLPROOFED BY CONFIGURATION.

8.) THE OXIDIZER BOOST PUMP IMPELLER K.E. SEAL RING IS READILY REPLACEABLE IF DAMAGED.

9.) THE OXIDIZER BOOST PUMP FORWARD ROLLER BEARING SHOULD HAVE A PULLER GROOVE ON THE INNER RACE TO FACILITATE REMOVAL.

10.) THE GEAR RETAINING BOLT SHOULD HAVE A BIGGER WRENCH FLAT TO PREVENT DAMAGING THE BOLT HEAD DURING INSTALLATION AND REMOVAL.

11.) THE OXIDIZER BOOST PUMP BALL BEARING SHOULD HAVE A PULLER GROOVE IN THE OUTER RACE TO FACILITATE REMOVAL.

12.) THE BOOST PUMP GEAR IS FOOLPROOFED BY CONFIGURATION, IF IT IS INSTALLED BACKWARDS THE RETAINING BOLT WILL INTERFER WITH THE COUPLING SHAFT

13.) THE PLANETARY GEAR ROLLER BEARING SHOULD HAVE PULLER GROOVES ON THE INNER RACE RETAINER RINGS TO FACILITATE REMOVAL.

FOLLOW UP

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVE CAT IIA

LAYOUT NO. 228436 TITLE

SHT. 1 OF 1 CHG. DESIGNER

REVIEWED BY W. QUIGLEY EXT. DATE

14) THE PUMP HOUSINGS ALL APPEAR TO BE FOOL-PROOFED BY CONFIGURATION.

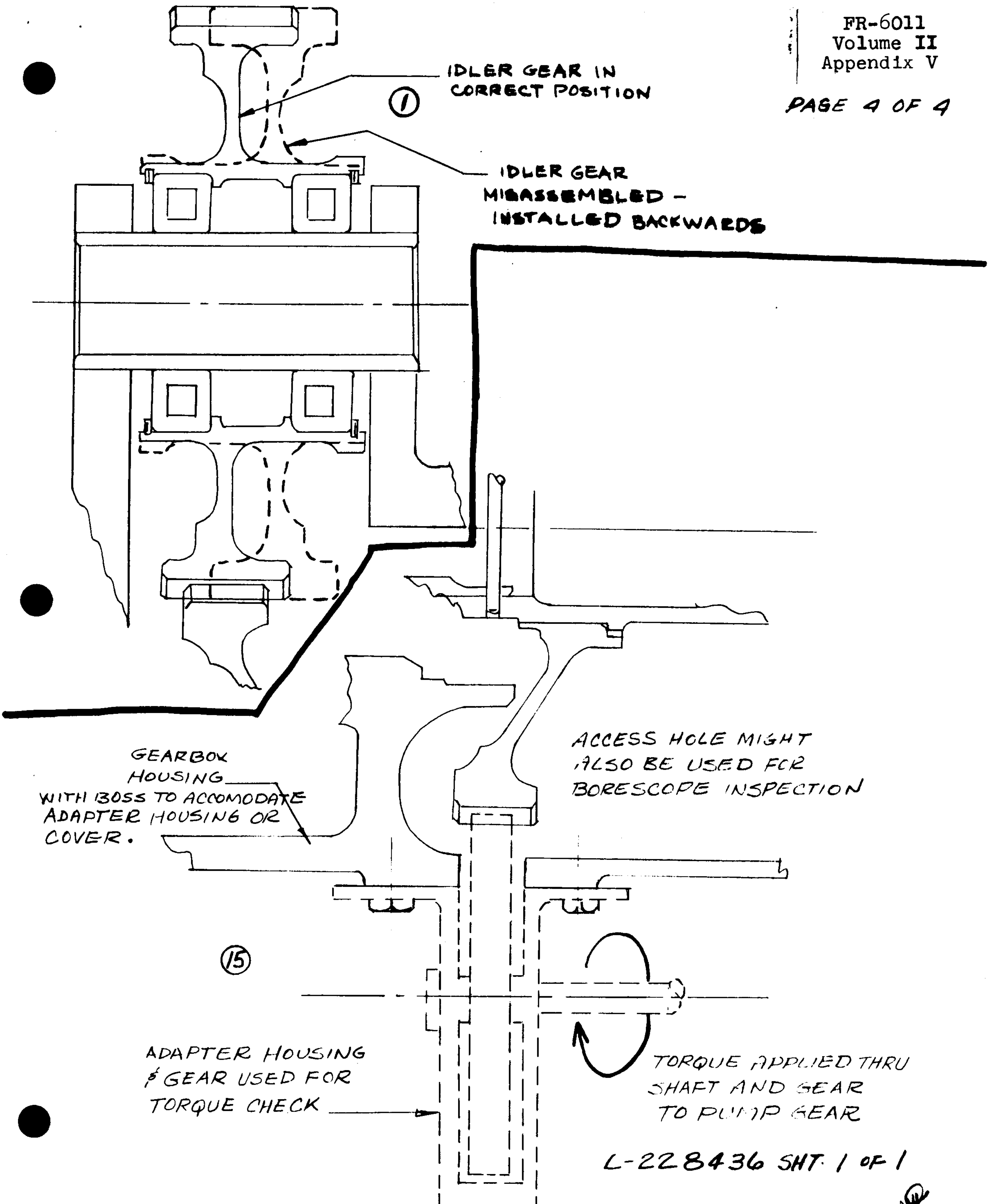
15) THE HOUSINGS SHOULD INCLUDE PROVISIONS TO PERMIT BORESCOPE INSPECTION OF BEARINGS AND ACCESS IS NEEDED TO ALLOW FOR A TORQUE CHECK WITHOUT DISASSEMBLY.
SEE SKETCH.

16) ELIMINATE THE RIVET LOCK AND USE A TAB LOCK SAFETY ON THE MAIN PUMP BALL BRG RETAINER NUT.

17.) THE SEAL PACKAGE STACKS SHOULD BE FOOLPROOFED TO PREVENT MIS-ASSEMBLY.

18.) BEARINGS SHOULD BE FOOLPROOFED TO PREVENT MIS-ASSEMBLY.

FOLLOW UP


IDLER GEAR IN CORRECT POSITION
1
IDLER GEAR MISASSEMBLED - INSTALLED BACKWARDS
GEARBOX HOUSING WITH BOSS TO ACCOMODATE ADAPTER HOUSING OR COVER.
ACCESS HOLE MIGHT ALSO BE USED FOR BORESCOPE INSPECTION
15
ADAPTER HOUSING & GEAR USED FOR TORQUE CHECK
TORQUE APPLIED THRU SHAFT AND GEAR TO PUMP GEAR
L-228436 SHT. 1 OF 1

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RLIO DERIVATIVE IIA, IIB, IV — PAGE 1 OF 2

LAYOUT NO. 228480 — TITLE RLIO DERIVATIVE II VALVES
SHT. 1 OF 2 — CHG. NC — DESIGNER R.M. LOWMAN
REVIEWED BY W. QUIGLEY — EXT. 3240 — DATE 8-17-73

INTENT: PROVIDE A PRELIMINARY DESIGN OF THE RLIO DERIVATIVE II CONTROL VALVES.

1) GASEOUS OXIDIZER VALVE:

(a) THE VALVE IS FOOLPROOFED BY CONFIGURATION, IF THE VALVE IS MOUNTED IN THE WRONG POSITION THE VENT LINE FITTING WILL BE 90° OUT OF POSITION.

2) OXIDIZER FLOW CONTROL VALVE:

(a) THE VALVE IS FOOLPROOFED BY CONFIGURATION, THE END FLANGES HAVE DIFFERENT BOLT CIRCLE DIAMETERS, (2.2 DIA VS. 2.5 DIA APPROX.).

3) OXIDIZER INLET SHUTOFF VALVE:

(a) THE VALVE IS FOOLPROOFED BY CONFIGURATION, THE INLET AND OUTLET SIDES HAVE DIFFERENT MOUNT STUD PATTERNS.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVE IIA, IIB, IV

LAYOUT NO. 228480 TITLE
SHT. 1 OF 2 CHG. NC DESIGNER
REVIEWED BY W. QUIGLEY EXT. DATE

4) FUEL INLET SHUTOFF VALVE:

(a) THE VALVE IS FOOLPROOFED BY CONFIGURATION, THE INLET AND OUTLET SIDES HAVE DIFFERENT MOUNT STUD PATTERNS.

(b) THE OXIDIZER AND FUEL INLET SHUTOFF VALVES CANNOT BE INTERCHANGED, THE FUEL VALVE IS SMALLER THAN THE OXIDIZER VALVE.

FOLLOW UP

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVE IIA, IIB, IV PAGE 1 OF 1

LAYOUT NO. 228480 TITLE RL10 DERIVATIVE II VALVES
SHT. 2 OF 2 CHG. NC DESIGNER WAYNE EASTMAN
REVIEWED BY W. QUIGLEY EXT. 3240 DATE 8-17-73

INTENT: SEE MELR FOR LAYOUT SHT. 1

1) TURBINE BYPASS VALVE:
   (a) THE VALVE IS FOOLPROOFED BY CONFIGURATION.
   (b) THE VALVE FLANGE SHOULD HAVE AN OFF-SET MOUNT HOLE TO PREVENT INTERCHANGING THE HELIUM & VENT LINE CONNECTIONS, OR USE TWO DIFFERENT SIZE ADAPTERS.

2) TANK PRESSURIZATION VALVE (FUEL & OXIDIZER):
   (a) THE VALVE SHOULD HAVE DIFFERENT SIZE INLET AND OUTLET ADAPTERS TO PREVENT INSTALLING THE VALVES BACKWARDS AND INTERCHANGING THE CONNECTIONS.
   (b) THE FUEL & OX PRESSURIZATION VALVES ARE INTERCHANGEABLE.

3) NOZZLE COOLANT VALVE:
   (a) SAME NOTE AS ITEM 2(a) ABOVE.
   (b) THE NCV CAN BE INTERCHANGED WITH THE PRESSURIZATION VALVES, FOOLPROOFING IS REQUIRED TO PREVENT MISASSEMBLY.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 CAT IV, IIA, IIB PAGE 1 OF 1

LAYOUT NO. 228368 TITLE QUICK DISCONNECT NOZZLE FEED SYSTEM

SHT. 1 OF 1 CHG. NC DESIGNER W. EASTMAN

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 8-24-73

INTENT: PROVIDE A QUICK DISCONNECT COUPLING FOR THE NOZZLE FEED SYSTEM OF THE RL-10 CAT IV WITH THE EXTENDIBLE NOZZLE.

1) THE VALVE SPANNER NUTS WILL REQUIRE A TABLOCK SAFETY.
2) THE SPANNER NUTS NEED FOOLPROOFING - THEY CAN BE INTERCHANGED AND THEY CAN BE INSTALLED UPSIDE DOWN.
3) THE VALVES NEED FOOLPROOFING - THEY CAN BE INTERCHANGED.
4) THERE APPEARS TO BE AN ADEQUATE LEAD IN TO ENSURE PROPER VALVE ALIGNMENT.

FOLLOW UP

PWA 10696D Rev. _0-71

Appendix V

Section II

Copies of Inactive Maintainability
Engineering Layout Review Forms

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIV. IIA, IIB, IV PAGE 1 OF 1

LAYOUT NO. 228062 TITLE OXIDIZER HEAT EXCHANGER RL-10 CAT II

SHT. 1 OF 2 CHG. NC DESIGNER W.R. FRANCIS

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 5-3-73

INTENT: PROVIDE AN OXIDIZER HEAT EXCHANGER.

1) THE HEX IS A BRAZED AND WELDED ASSEMBLY WITH NO APPARENT MAINTAINABILITY PROBLEMS. ADDITIONAL INFORMATION IS REQUIRED IF A COMPREHENSIVE MAINTAINABILITY ASSESSMENT IS TO BE MADE. WHEN THE DESIGN IS FIRMED UP THE FOLLOWING AREAS WILL BE SURVEYED.
   (a) ENGINE MOUNTING LOCATION WITH RESPECT TO ACCESSIBILITY FOR TROUBLE SHOOTING AND EASE OF REPLACEMENT IN AN INSTALLED ENVIRONMENT.
   (b) HEX MOUNT SCHEME (ACCESS AND FASTENERS).
   (c) FLUID LINE CONNECTIONS, (FASTENERS AND ACCESSIBLITY).
   (d) REPAIR CONSIDERATIONS.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIV IIA, IIB, IV PAGE 1 OF 1

LAYOUT NO. 228062 TITLE OXIDIZER HEAT EXCHANGER RL-10 CAT II

SHT. 2 OF 2 CHG. NC DESIGNER W.R. FRANCIS

REVIEWED BY W. QUIGLEY EXT. 3240 DATE 5-3-73

INTENT: PROVIDE A PRELIMINARY DESIGN OF A CURVED OXIDIZER HEAT EXCHANGER.

1) SAME NOTATIONS APPLY AS SHOWN ON MELR FOR SHEET 1.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIVATIVE IIA, IV LOX BOOST PUMP PAGE 1 OF 5
LAYOUT NO. 228118 TITLE WITH GH_2 TURBINE
SHT. 1 OF 1 CHG. NC DESIGNER WOODIE FRANCIS
REVIEWED BY W. QUIGLEY EXT. 3240 DATE 5-17-73

INTENT: PROVIDE A PRELIMINARY CONCEPTUAL DESIGN FOR A GH_2 TURBINE DRIVEN OXIDIZER BOOST PUMP. (SEE SHT. 5 FOR ITEM CALL-OUT)

1) THE HOUSING FLANGE SHOULD HAVE JACKSCREW HOLES TO FACILITATE SEPARATION.

2) THE TURBINE WHEEL IS FOOLPROOFED BY CONFIGURATION, BUT IT SHOULD HAVE A PULLER GROOVE OR THREADED HOLES TO FACILITATE REMOVAL.
THE KE SEAL RING CAN BE INSTALLED BACKWARDS, FOOLPROOFING IS NEEDED, (STEPPED DIAMETERS ?). ALSO NEED PULLER GROOVE OR THREADED HOLES.

3) THE BALL BEARING IS FOOLPROOFED BY CONFIGURATION, IF INSTALLED BACKWARDS THE SPANNER NUT CANNOT BE SEATED PROPERLY.

4) THE SEAL LAND RING IS FOOLPROOFED BY CONFIGURATION, BUT A PULLER GROOVE OR THREADED HOLES ARE NEEDED FOR REMOVAL.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIVATIVE

LAYOUT NO. 228118 TITLE
SHT. 1 OF 1 CHG. NC DESIGNER
REVIEWED BY W. QUIGLEY EXT. DATE

5) THE SEAL SPACERS SHOULD BE SYMMETRICAL SO THEY CAN BE INSTALLED EITHER WAY AND A PULLER GROOVE SHOULD BE ADDED.

6) THE SEAL SPACER IS FOOLPROOFED BY CONFIGURATION. A PULLER GROOVE OR THREADED HOLES SHOULD BE ADDED TO FACILITATE REMOVAL.

7) THERE DOESN'T APPEAR TO BE SUFFICIENT ROOM TO ALLOW EASY REMOVAL OF THE HOUSING LINER RETAINER PIN, THE PIN SHOULD BE INSTALLED AT AN ANGLE SIMILAR TO THE KE SEAL RING PIN. THE LINER SHOULD HAVE A PULLER GROOVE.

8) THE SEAL PLATE CAN BE INSTALLED BACKWARDS, NEED FOOLPROOFING, (STEP DIAMETER?).

9) THE IMPELLER KE SEAL RING IS FOOLPROOFED BY CONFIGURATION AND IT IS REPLACEABLE IF DAMAGED.

FOLLOW UP

PWA 10696D Rev. 10-71

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL-10 DERIVATIVE

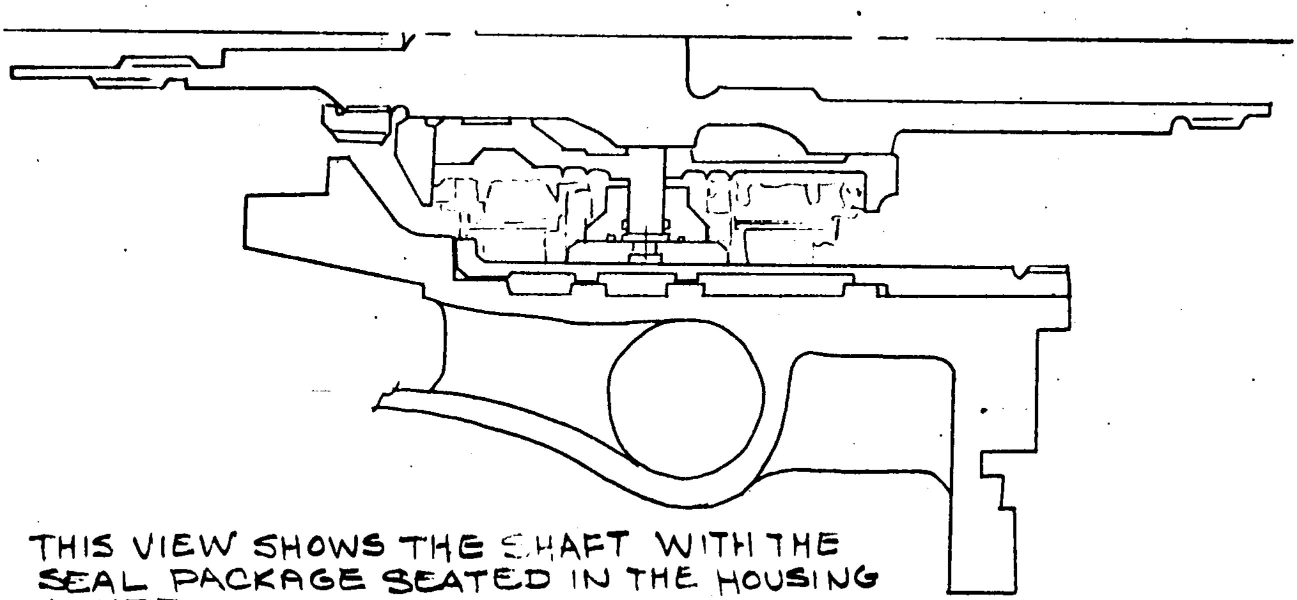
LAYOUT NO. 228118 TITLE
SHT. 1 OF 1 CHG. NC DESIGNER
REVIEWED BY W. QUIGLEY EXT. DATE

10) IT APPEARS THAT THE IMPELLER ROLLER BEARING CAN BE INSTALLED BACKWARDS, NEED FOOLPROOFING.

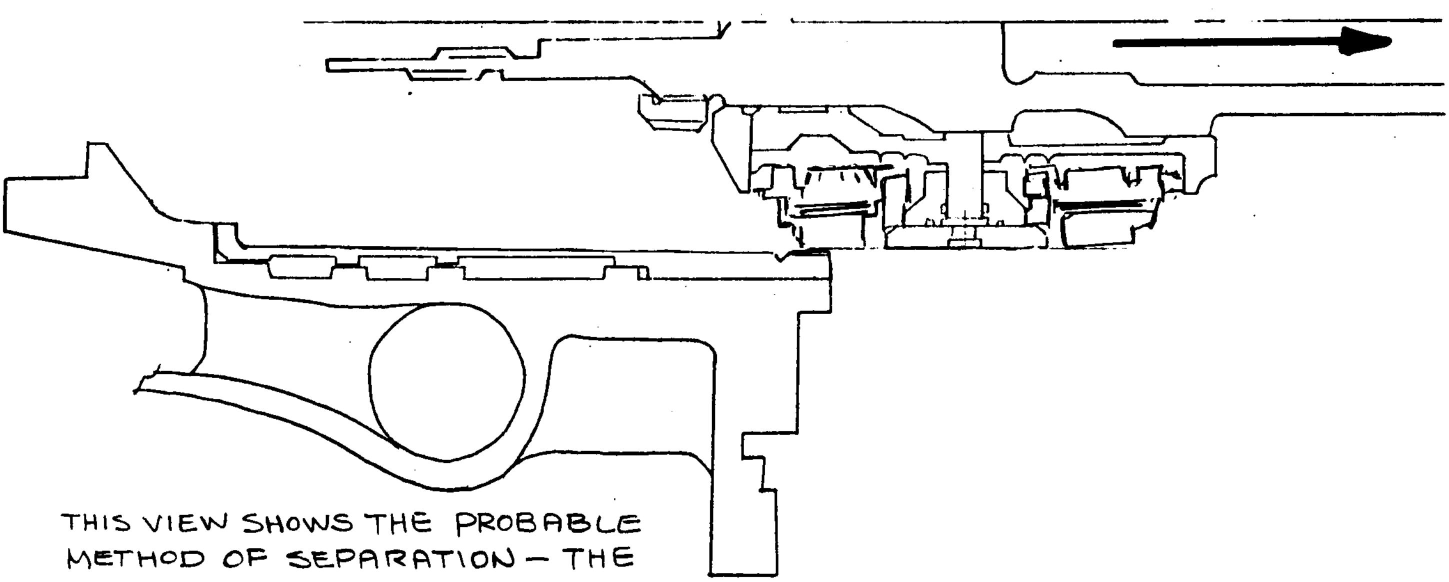
11) THE SEAL PACKAGE IS SUSCEPTIBLE TO DAMAGE DURING INSTALLATION AND REMOVAL.
IT APPEARS THAT THE SEALS AND SPACERS MUST FIRST BE ASSEMBLED ONTO THE SHAFT AND THEN THE SHAFT AND SEALS (AS A UNIT) ARE PUSHED ALONG THE LINER UNTIL THEY ARE SEATED.
THIS IS A BLIND ASSEMBLY AND THE SEALS COULD BE DAMAGED AS THEY SLIDE ALONG THE LINER. REMOVAL REQUIRES THAT THE SHAFT AND SEALS BE PULLED OUT OF THE HOUSING LINER AS A UNIT AND AGAIN SEALS WILL BE PRONE TO DAMAGE. THIS REFLECTS POOR ASSEMBLY AND DISASSEMBLY PRACTICE.
SEE ATTACHED SKETCH.

FOLLOW UP

PWA 10696D Rev. 10-71

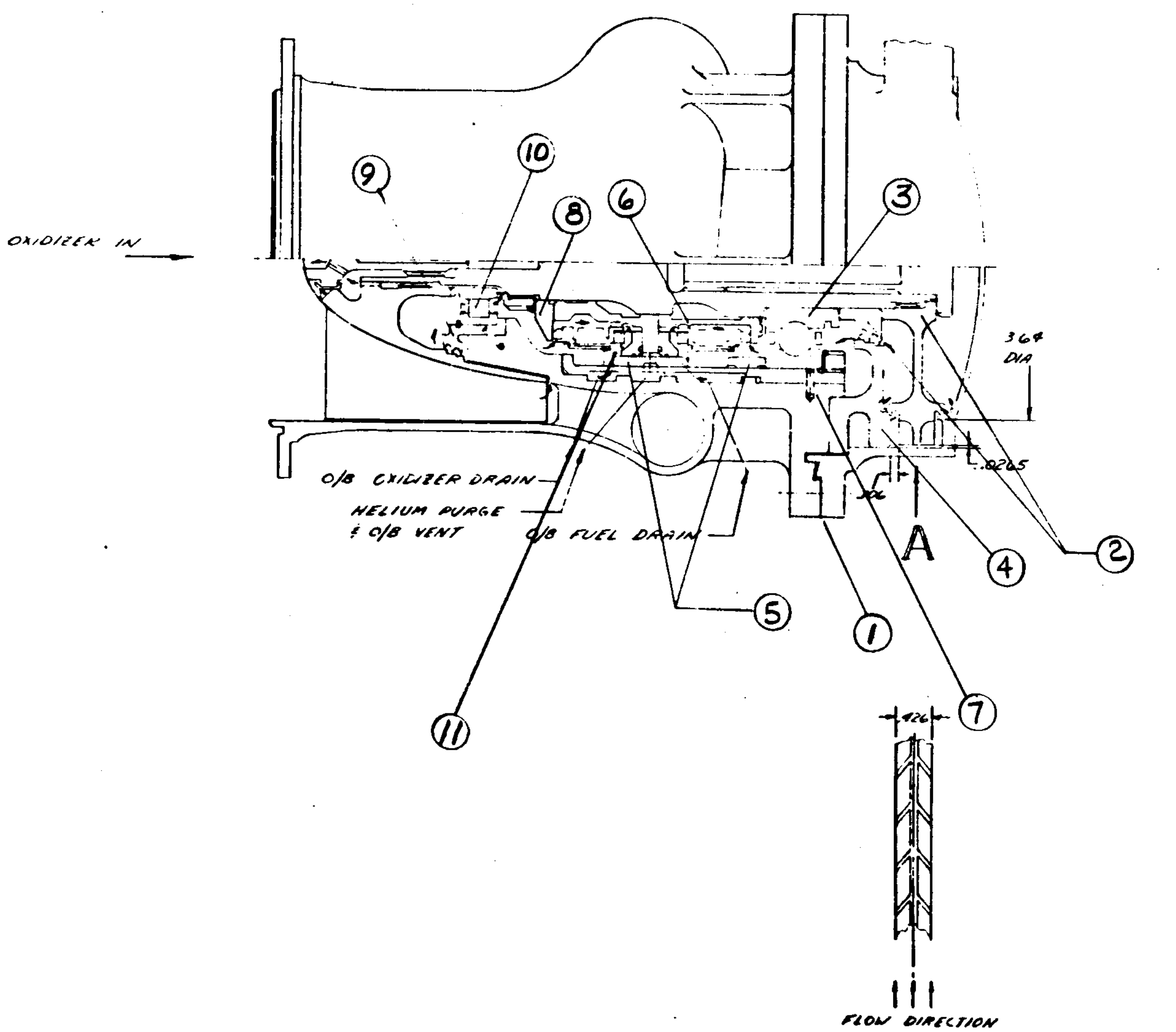


THIS VIEW SHOWS THE SHAFT WITH THE SEAL PACKAGE SEATED IN THE HOUSING LINER.



THIS VIEW SHOWS THE PROBABLE METHOD OF SEPARATION – THE SHAFT IS PULLED THROUGH THE HOUSING AND THE SEALS ARE DRAGGED ALONG THE LINER I.D.

MELR-228118-1
W. QUIGLEY
5-17-73



VIEW A

MELR-228118-1
W. QUIGLEY
5-17-73

MAINTAINABILITY ENGINEERING LAYOUT REVIEW

MODEL RL10 DERIVATIVE CAT IIA, IV PAGE 1 OF 1

LAYOUT NO. 228118 TITLE LOX BOOST PUMP WITH GH2 TURBINE
SHT. 1 OF 1 CHG. NC DESIGNER W. FRANCIS
REVIEWED BY W. QUIGLEY EXT. 3240 DATE 8-13-73

= SUPPLEMENT COPY =

1) PROVIDE ACCESS FOR INTERNAL BORESCOPE INSPECTION OF BEARINGS AND GEARING.

2) PROVIDE ACCESS TO ALLOW FOR A MANUAL TORQUE CHECK OF PUMP GEARTRAINS.

THE ABOVE ESSENTIAL INSPECTION REQUIREMENTS ARE TO BE ACCOMPLISHED WITH THE ENGINE INSTALLED IN THE SPACE TUG VEHICLE.

FOLLOW UP